Energy Research and Development Division

FINAL PROJECT REPORT

Integrated Solar PV, Vanadium Redox Flow Battery, and Microgrid Demonstration Project

California Energy Commission

Edmund G. Brown Jr., Governor

Month Year | CEC-500-2017-037

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ACKNOWLEDGEMENTS

Foresight Renewable Solutions (FRS) is grateful for the technical and financial support of the California Energy Commission for the Integrated Solar PV, Vanadium Redox Flow Battery, and Microgrid Demonstration Project.

FRS deeply appreciates the collaboration and support from the Naval Facilities Engineering Command's (NAVFAC) Expeditionary Warfare Center (EXWC), as well as the day-to-day collaboration with Mobile Utilities Support Equipment (MUSE) yard that hosted the project and provided daily technical support in building out the project. In particular, James Heller and his team at the EXWC were instrumental in moving forward with the project and to navigating cooperation across the Navy. Finally, without the daily management and technical savvy of the Navy SEABEES unit at the MUSE yard, the project would never have achieved fruition. FRS expresses its deep respect and gratitude to all of the servicemen and women as well as the civilian staff that work tirelessly and often without recognition to keep us safe every day.

FRS also acknowledges the tremendous efforts of our Engineering, Procurement and Construction Contractor, Pacific Data Electric (PDE), as well as Growing Energy Labs, Inc. (GELI), and Imergy Power Systems for their tireless dedication to completing a project despite substantial technical obstacles and difficulties, including the challenges that naturally emerge when trying to develop innovative new energy storage technologies. The technical vendors were second to none and contributed fundamentally to the vision and build-out of the project as well as getting it across the finish line.

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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Integrated Solar PV, Vanadium Redox Flow Battery, and Microgrid Demonstration Report is the final report for the Integrated Solar PV, Vanadium Redox Flow Battery, and Microgrid demonstration project (contract number PIR-12-004, grant number PON 12-502) conducted by Foresight Renewable Solutions and Growing Energy Labs, Inc. The information from this project contributes to Energy Research and Development Division's Environmentally Preferred Advanced Generation Program.

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ABSTRACT

A barrier to increasing penetration of intermittent renewable generation on electric grids is having dispatchable resources to offset the variability of renewable output across a range of time scales. Without these firming resources, grid stability is compromised as more renewable generation is added. This report explores the viability of using long-duration flow batteries to "firm" or guarantee renewable generation in a community microgrid. A microgrid including solar generation and vanadium redox flow batteries was installed and tested at the U.S. Naval Facilities Expeditionary Warfare Center's (EXWC's) Mobile Utilities Support and Equipment (MUSE) Facility at the Naval Base Ventura County. In grid-connected mode, the batteries absorbed short-term solar output fluctuations that would otherwise be transferred to the utility, contributing to grid instability. Stored energy from these long-duration batteries was released during peak hours to offset loads, helping grid operators manage multi-hour load balancing challenges, and providing cost-savings for its host community. In grid-disconnected mode, the batteries' shorter-duration firming and longer-duration time-shifting capabilities allowed the system to continuously maintain microgrid stability and serve community loads, even when solar generation was highly variable. This community-scale microgrid project, including solar generation and long-duration flow batteries, maximized renewable electricity by the community microgrid while creating a more stable, secure and disaster-resilient electricity system. Substantial host-community utility cost-savings were also demonstrated. Broader deployment of similar systems would incrementally create the same benefits at the statewide grid level.

Keywords: microgrid, vanadium redox flow, battery, energy storage, community, renewable, resilience

Citation: Byrne, Warren; Smith, Brad; Wartena, Ryan; Moy, Kevin; Pineda, Carlos. Foresight Renewable Solutions, LLC and Growing Energy Labs, Inc. 2017. ***Final Report for the Integrated Solar PV, Vanadium Redox Flow Battery, and Microgrid Demonstration Project.*** California Energy Commission. Publication number: CEC-500-2017-037.

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EXECUTIVE SUMMARY

Introduction

California has been a dynamic force for shifting to sustainable and renewable energy sources, including solar and wind, to reduce greenhouse gas emissions. In the past several years, there has been explosive growth, particularly in solar installations. Electricity, regardless of energy source, must be used the instant it is generated, which makes solar and wind resources challenging to manage on the power grid. Power from these renewable generation sources is generated at different times and does not always align with electricity demand.

The next step in this fast-moving shift towards a sustainable grid is energy storage technology. This technology harnesses energy and stores it when consumption is low and feeds it back to the grid when required at peak demand times or to supplement when there are unanticipated changes in renewable energy production. Microgrids are fast becoming the vehicle to incorporate and advance energy storage technology, effectively connecting renewable energy to the grid and allowing local users more control over using power sources.

Microgrids are small-scale, independent power-generating equipment. These systems are managed by controllers that monitor and balance electricity demand and supply and storage. They are typically used to support facilities with critical electricity needs like hospitals, military installations, industrial complexes or university campuses. Microgrids can disconnect from the traditional grid (islanding), efficiently integrate renewable resources and strengthen grid resilience. Additionally, using regional energy resources for local demand helps reduce energy losses in transmission and distribution while helping mitigate disruptions. The most common source of generation is solar photovoltaic (PV).

Project Purpose and Process

Typical renewable generation installations at community or utility facility levels do not include energy storage, relying instead on the utility grid to absorb and balance intermittent renewable generation. These installations cannot provide back-up power in the event of a grid outage and do not increase energy security or reliability for the host community. In fact, larger levels of intermittent renewable generation at the distributed/community and utility scale is challenging grid stability statewide and is a critical barrier to installing more renewables in California.

High amounts of intermittent renewables also create load balancing challenges with consumer electricity use patterns that are shifting towards a later evening peak. While PV can provide substantial amounts of electricity during daylight hours, as the sun sets, PV production decreases rapidly, just as the majority of California residents are returning home from work and switching on home loads. This demand shift results in electricity peak between 5 and 9 pm, and because there is little energy storage, can create a statewide grid-balancing problem. Such load-balancing issues can be amplified even further at the community microgrid scale when the microgrid is disconnected or “islanded” from the grid.

Emerging modular flow batteries for energy storage technology show promise to help solve the short and long system stability and balancing challenges. Commercialized energy storage technologies include the shorter-duration technologies that are well adapted to power intensive uses cases (primarily fly-wheels and various fixed-cell battery chemistries, including lithium-ion and lead-acid), and the longer duration, high energy capacity technologies including pumped hydro, compressed air energy storage, and various flow battery technologies.

To explore these challenges, a community-scale microgrid system, integrated with solar PV generation and supported by modular long-duration flow batteries was designed, installed and tested at the Naval Base Ventura County, a military base at Port Hueneme, California. The project team, led by Foresight Renewable Solutions, used locally available renewable energy with the microgrid system to demonstrate the storage technology and islanding capability. The project originally included 100kW/1,000kWh of flow batteries; however, the final installed storage capacity was reduced to 100kW/420kWh.

In grid-connected mode, the microgrid charged the batteries from the PV generation, absorbing the short-term generation fluctuations that would otherwise be passed up to the grid, potentially causing feeder instability and power quality issues. Stored energy was later released during peak hours to offset loads, effectively shifting the microgrid's facility loads to off-peak hours. This helps grid operators manage their multi-hour load balancing problems, while creating cost-savings for the host community by moving consumption and peak demand from higher-cost periods to lower-cost periods under the applicable utility tariff.

In island-mode testing, the microgrid successfully disconnected from the grid during simulated grid outages and continuously served critical loads while maintaining power quality and stability, even when solar generation was highly variable. This microgrid emergency back-up power capability showed that even full facility loads could be served almost indefinitely, without grid power and without fossil-fueled backup generators, given appropriate microgrid sizing of the PV generation and battery storage components. As in grid-connected mode, the long-duration flow batteries absorbed sub-hourly and sub-minute PV generation fluctuations while charging and over longer periods were able to discharge power to serve facility loads when they occurred.

Project Results

The project team successfully designed, constructed and tested a solar PV/long-duration flow battery microgrid system at the Naval Base Ventura County facility.

Capital costs of the project were measured and documented as part of the project budgeting process. The project team successfully commissioned the system and ran it through a full range of testing protocols. The Geli digital Energy Operating System successfully controlled the charge and discharge of the Imergy Power System flow batteries, performing constant power charge and discharge limit tests. Direct current (DC)-to-Alternating current (AC) round-trip efficiency above 75 percent was achieved. Although full system AC-to-AC round trip efficiency was lower than expected (45- 50 percent), the project team anticipates improvements to the battery inverter and reducing the inverter and battery parasitic ancillary loads will substantially improve the round-trip efficiency in commercialized systems.

The project also successfully tested two durations with the system running in Microgrid/Island Mode. The tests demonstrated this system can serve critical loads for potentially indefinite periods without grid power. The system showed it could actively "island" during simulated grid outages, only momentarily dropping power while the microgrid disconnected from the grid. The system consistently maintained loads when re-establishing grid signal and reconnecting to the grid. Perhaps most importantly, the system validated firm intermittent solar generation in islanded mode, maintaining consistent power to loads using only PV solar and battery power, even when the solar generation output fluctuated dramatically or was suddenly interrupted.

The results of the Microgrid/Island Mode testing determined that properly scaled renewable plus storage microgrid systems can offer emergency back-up power and long-term resiliency, without requiring fossil fuel back-up generators. In fact, since this project, solar plus storage systems for resiliency have rapidly gaining popularity at the commercial & industrial, as well as the residential scale, and are now being offered by several California companies, including project participants Geli and Pacific Data and Electric.

Several test cycles in grid-connected mode demonstrated the Geli system controller was capable of peak-shaving and time-shifting of loads using battery system dispatch. Extensive system performance modeling using measured Mobile Utilities Support and Equipment facility loads and the applicable Southern California Edison tariff structure conducted during this project indicated that utility savings in the 30 percent range would be achieved.

Project Benefits

The project successfully demonstrated that a community-scale microgrid integrating PV solar generation and long-duration flow batteries can act to simultaneously maximize renewable energy and create a more stable, secure and disaster resilient electricity system at the community and the statewide grid levels.

This model, if replicated at critical community first-responder facilities such as hospitals, police stations, or fire departments, would dramatically increase community-wide disaster resilience. For businesses, in addition to the utility cost-savings created in grid-connected mode, the ability to continue operations during extended grid outages could prevent massive losses by avoiding work stoppages. Installations in residences and various facilities would increase stability and resilience statewide, while maximizing renewable resources and environmental and economic benefits.

The project also significantly advanced scientific knowledge and integrating practical renewable energy technology with flow batteries.

CHAPTER 1: Project Administration

This chapter describes the overall organizational structure of this project, specifically the project participants and the respective roles are outlined.

Foresight Renewable Solutions (FRS) served as Prime Contractor for this project, including the conceptualization and preliminary design for several iterations of the project. Overall project Management role for such activities as project origination & concept, high level design, team origination, maintaining the schedule, project permitting, making sure all parties were coordinated in their efforts, and administrative activities like invoicing and progress reporting to the California Energy Commission (Energy Commission). Importantly, FRS also managed the installation and decommissioning of the system, insuring that all individuals had base access by getting the base security office all requisite information with adequate lead times.

Pacific Data and Electric (PDE) Total Energy Solutions was the General Contractor and Belco Electric was PDE's electrical subcontractor for the installation. PDE was responsible for doing the final electrical & construction design for the system, and with FRS, getting it approved by the Navy. For the installation PDE worked with FRS in coordinating the shipping of all materials and equipment to the site. PDE was responsible for the physical placement of all equipment within the project footprint, among many other things like running Ethernet cables from each device to the web relay cabinet. Belco was responsible for installing the solar on top of the open-faced shipping containers and doing all the wiring for the entire system. PDE also performed the system decommissioning activities.

Imergy Power Systems was responsible for significant input into the design of the system, supporting the installation and integration of their battery units into the microgrid system, troubleshooting problems that arose, and supporting PDE in their efforts to decommission the system.

Growing Energy Labs, Inc. (Geli) was responsible for working out the details with PDE and Imergy regarding the system design and functionality as well as the integration of their energy controls software designed to manage the functionality of the entire microgrid system (PDE and Belco did the physical installation of the Geli software console at the site). Geli was instrumental in conducting the project-testing plan, gathering data and creating this Final Report to the Energy Commission.

U.S. Naval Facilities Expeditionary Warfare Center's (EXWC's) Mobile Utilities Support and Equipment (MUSE) Facility at the Naval Base Ventura County (NBVC) supplied the project site and requisite human resources to get the project approved by the appropriate authorities, as well as provided assistance with getting base access for all necessary parties. EXWC had also committed to build a microgrid infrastructure encompassing the MUSE facility, including permitting the utility interconnection with Southern California Edison, as well as 100 kW of PV Solar capacity during the grant period. This system, called the Microgrid Test Bed (MTB) by

EXWC was to be integrated with the project and counted as matching funding toward the Grant.

Unfortunately, due to vendor and contracting problems, EXWC was unable to commence the MTB project within the schedule window of this grant. Since then, these issues have been resolved and PDE was awarded the project by the Navy. The MTB project is funded and as of this writing was in the final engineering design phase with construction planned to begin later in 2017.

CHAPTER 2:
MUSE facility Study and Operational/ Economic Model

This chapter reviews the projects achievement of amended Work Statement Task 2 and its various subtasks. All these items were successfully completed.

2.1 MUSE facility Study

The Mobile Utilities Support and Equipment (MUSE) facility Loading Study was completed in February 2014 and analyzes operating patterns, electricity needs and utility costs of the EWEC's MUSE facility, as well as analyzing operation of a military integrated microgrid system. The project team collected historical utility bills from the MUSE facility and the greater Naval Base Ventura County (NBVC) to determine the average utility rates, demand charges and other criteria which were then used in the Operational/Economic Model to analyze and predict cost savings opportunities available through installing and operating the project grant-funded demonstration scale, as well as hypothetical larger systems optimized to accommodate full MUSE and NBVC loads.

MUSE facility personnel were interviewed to identify critical loads that should be targeted for support by the system for "indefinite survivability" via installation of the project. This information was used to establish project design parameters and a preliminary equipment list. The full MUSE facility Study is can be found in Appendix A.

2.2 Operational & Economic Model

Foresight Renewable Systems (FRS) developed a flexible spreadsheet-based Operation/Economic model (OE model) of the proposed hybrid technology configuration to predict the operational and financial performance of the system. The OE model was designed to accommodate a range of variable inputs including: community electricity usage patterns and costs, equipment component capacities, operational characteristics, renewable resource and generation production estimates, and financing assumptions. The OE model was used to assist in component sizing and development of operational protocols for the project, and to set operational and financial benchmarks against which to measure actual performance.

The OE model was also designed to function as a tool that can be used by other communities in planning, designing, and financing similar projects at varying scales and with different host community baseline conditions, including the potential expansion of the project to include other facilities at the NBVC.

The OE model was used to prepare the MUSE facility Study Report that: (1) included projected utility cost savings from the operation of the demonstration projects, including savings from increased penetration of locally available solar PV, displacement of utility power during peak periods (load-shifting), and peak-shaving; and (2) indicated which critical loads could be served by the demonstration project when in islanded mode and for how long.

The OE model was loaded approximately one calendar year of 15-minute interval load/demand data for the MUSE facility as well as with the applicable Southern California Edison (SCE) tariff structure, including seasonal time-of-use (TOU) energy charges and demand charges. Operational performance assumptions were made regarding the energy storage units (expected to be compressed air energy storage at the time of the Faculty Study) as well as for the PV generation planned for installation. Performance assumptions for the storage units included round-trip efficiency, as well as charge and discharge rate and capacity limits. These assumption levels were generally exceeded during the performance measurement phase for the Imergy flow batteries that were finally installed as the project energy storage units. Accordingly, MUSE facility the cost-savings results projected by the OE model should be viewed as slightly conservative versus what would be achievable through continued operation of the project as installed.

Solar PV output was also projected using industry-standard PVSyst software and NREL Typical Meteorological Year (TMY) input data sets from the nearby Pt. Magu weather station. Hourly production was projected for each of the 8,760 hours in a typical year for that specific solar resource based on input assumptions for the specific PV system equipment planned for installation including PV modules, racking aspect and tilt, and inverters. This energy production estimation approach has been proven as highly accurate for long term PV system output in the majority of utility and commercial scale PV generation systems installed nationwide to-date.

2.2.1 Modeled and Project-Adjusted Utility Cost-Savings

The cost-saving modalities modeled were based on operating the project for one calendar year in grid-connected mode and included load displacement (related to photovoltaic (PV) generation), load-shifting (energy use moved from one TOU period to another via dispatching the energy storage) and peak-shaving (reduction of monthly 15 minute peak demand via dispatch of the energy storage).

The final capacities of the energy storage and PV generation installed for the project were lower than those assumed in the OE model. However, due to the level of accuracy of the performance assumptions for the energy storage units and the PV generation, the levels of savings projected can be reasonably scaled proportionally to the capacities finally installed (Table 1). Regarding the PV generation, the modeled capacity was 150kW and the capacity installed during the grant period was 42kW, therefore the load-displacement cost-savings related to the addition of PV only can accurately be scaled to 28% of those predicted by the OE model. The final capacity of the energy storage installed was 420 kWh versus 1000 kWh assumed in the model, so the load-shifting and peak-shaving cost savings related to the energy storage capacity can accurately be scaled to 42% of those predicted by the OE model. The savings levels shown incorporate the MUSE Facilities utility costs are comprised 63% by energy related charges and 37% demand charges.

Table 1: MUSE Facility: Projected Utility Cost Savings

	OE Model	Project-Adjusted
Load Displacement	22.0%	6.2%
Peak Shaving (PV only)	4.3%	1.2%
Peak Shaving (PV + Storage)	13.3%	5.6%
Load Shifting	3.3%	1.4%
Total Projected Savings	38.7%	13.2%

Note: Project-Adjusted results assume equipment capacities as-built.

2.2.2 Energy Cost Savings

Energy cost savings are created through both load-displacement and load-shifting. Figure 1 below shows estimated monthly energy charges in three scenarios at MUSE: (1) prior to project implementation, (2) after integration of 150KW solar PV, and (3) with the addition of storage (shown as CAES). Storage saves energy charges during the summer rate months due to load shifting between lower and higher TOU periods. Load-shifting savings are not possible during winter rate months given both the low cost differential between off-peak and mid-peak energy rates and the expected round-trip efficiency losses of the energy storage unit.

Figure 1: Energy Use After Load-Displacement and Load-Shifting

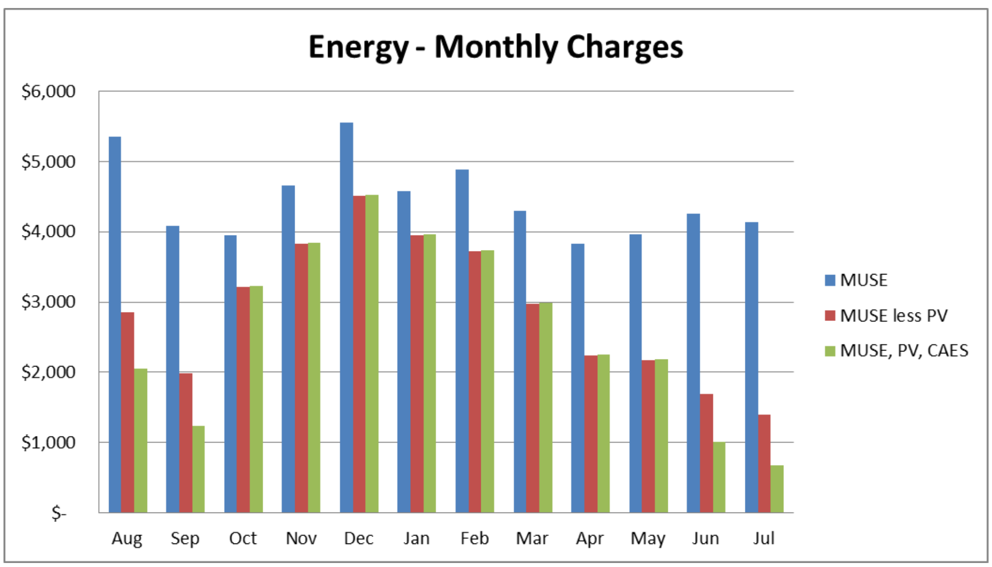
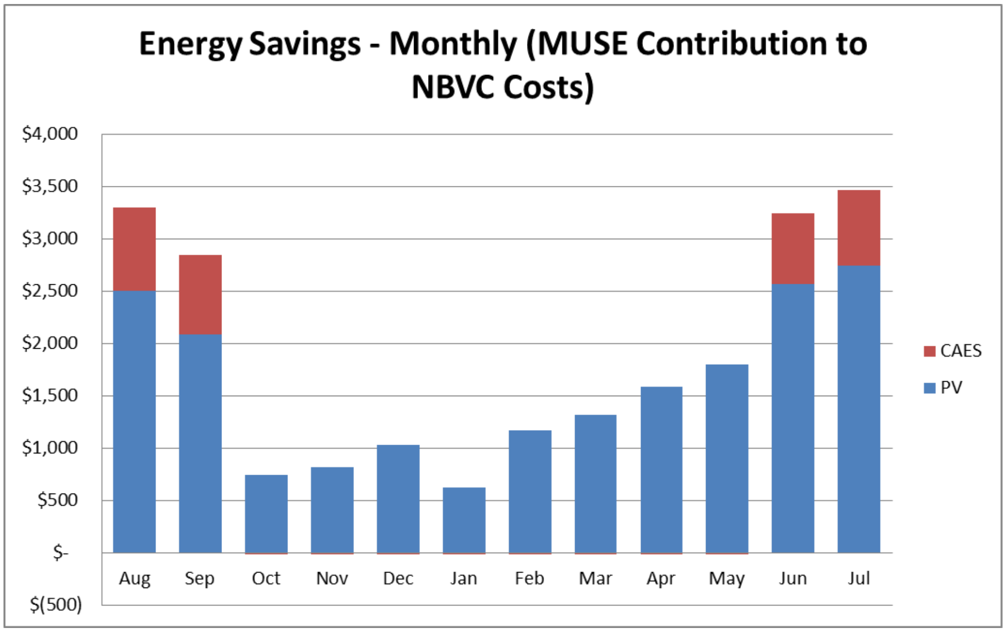


Figure 2 shows that the savings from storage-enabled load-shifting are concentrated in the summer rate months (June-September) and negligible during winter rate months. However, some level of energy savings occurs in every month due to PV load displacement.

Figure 2: Monthly Energy Savings (MUSE Contribution to NBVC Savings)



2.2.3 Peak-Shaving

To maximize peak-shaving benefits, we change energy storage operating protocols given different SCE rate structures during the summer and winter rate months, with higher charges during mid- peak and the highest charges during peak hours. During the summer (as defined by SCE rate includes June, July, August, September), peak hours occur from 12-6pm, mid-peak hours are 8am to 12pm, and 6pm to 10pm, and off-peak is from 10pm to 8am. During the winter (as defined by SCE rate, winter includes all other months), there are no peak hours, mid-peak hours occur from 8am to 8pm, and off-peak hours occur from 8pm to 8am. Peak-shaving protocol logic is as follows:

1. Summer Rate Months: Charge energy storage daily during off-peak week and weekend hours that show low probabilities of the occurrence of peak demand events. On a general basis, assume discharge of energy storage in one mid-peak hour every other week-day, to cover the probability that NBVC is trending toward a monthly peak demand event in any given mid-peak hour and discharge the remaining stored energy in on-peak hours to maximize load-shifting benefit. We assume that the exact hours of discharge are more specifically controlled in response to signals from Base Command that the NBVC is trending toward a peak load event.

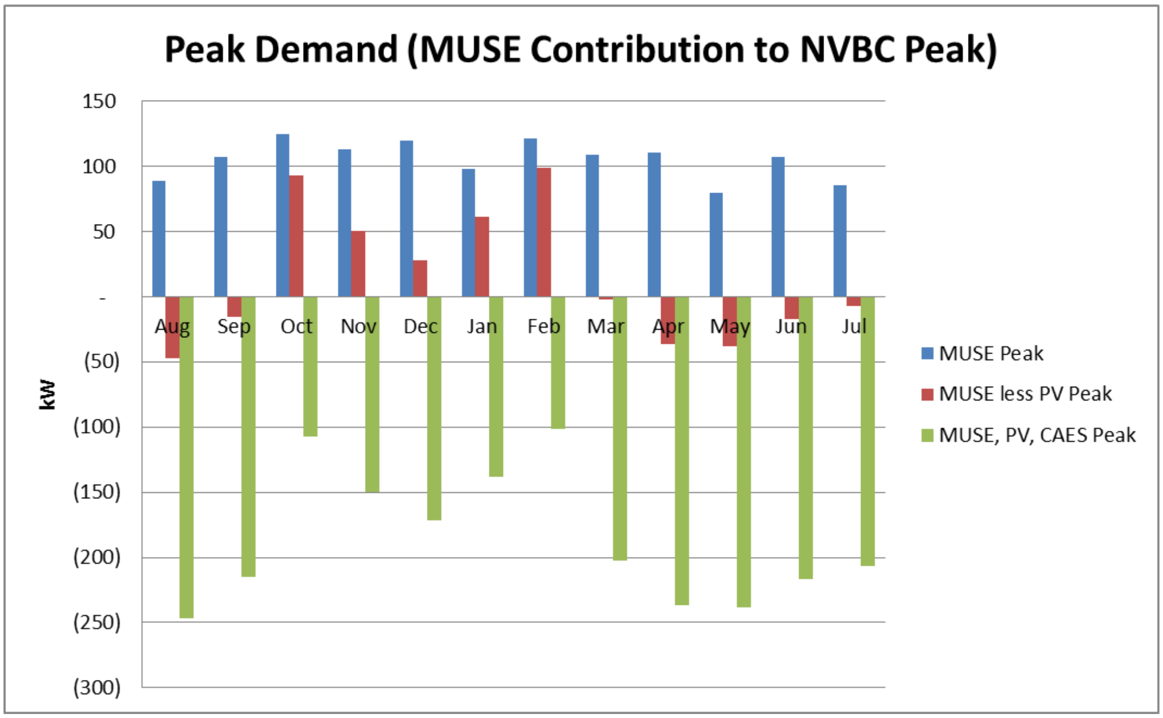
2. Winter Rate Months: Charge energy storage weekly during low-load weekend hours. Discharge during mid-peak hours, as needed, when receiving a signal that NBVC loads are approaching high-peak levels and a monthly peak load event is likely in progress.

It's important to note that these demand charge savings were calculated at Naval Base Ventura County level where average demand was 4,900 kW and average peak demand was 7,530 kW.

This allowed the full benefit of demand charge management using a battery system of this capacity. The model assumed the system would retain enough stored energy for peak-shaving purposes to release 200 kW for 45 minutes per day, trimming NBVC monthly peak demand by an average of 186 kW. At the MUSE facility 250kW/1,000kWh hours of storage was substantially oversized for demand charge management, given that average demand was 94 kW and average peak demand was 172 kW.

The result of demand at the MUSE facility being pushed down below zero during the peak demand periods for NBVC is shown in Figure 3. These "below zero" reductions in demand at MUSE would accrue to the NBVC master meter billing, as the MUSE facility is sub metered and changes in net energy use and peak demand are rolled up to the NBVC for billing purposes. Average peak demand for the NBVC was 7,530 kW, so these circa 185kW reductions could always be fully used to reduce NBVC demand charges.

Figure 3: Peak Demand (MUSE Contribution to NBVC Peak)



2.2.4 Demand Charge Savings

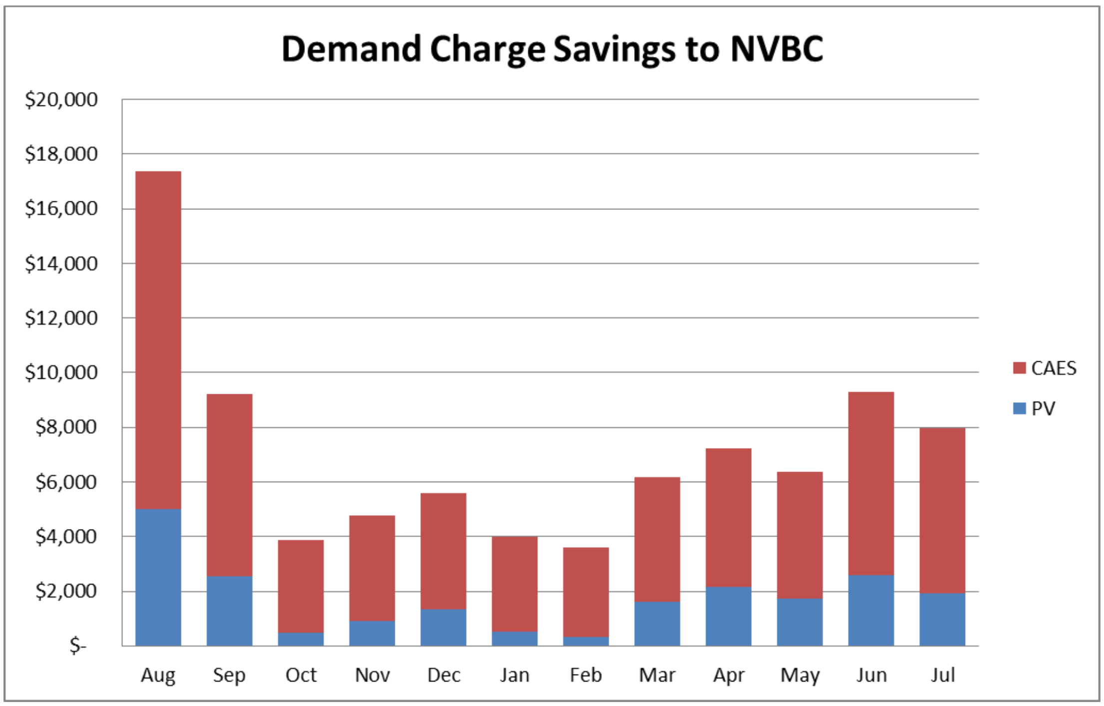
As noted in the Load Displacement section, the 150kW PV output typically does a good job a creating energy savings, and also contributes to demand charge savings, given the general coincidence of solar to peak rate periods, particularly in the summer.

Regarding operation of the energy storage, a simplifying assumption was applied for the peak shaving scenario regarding the existence of a smart load monitoring system at NBVC level that can provide a warning signal to the project controls in hours when the Base is trending toward a monthly peak demand event. It is assumed this occurs in one hour every other weekday during the mid-peak hours in summer months (as defined in SCE rate).

The Base typically peaks in each month between the hours of 8am and 1 am with occasional peaks as late as 2 pm. By assuming the existence of smart monitoring and intelligent controls, as described above, accurate dispatch of energy storage is shown to reduce NBVC peak demand by 200kW each month. Peak coincident production by PV will create greater demand reductions as previously shown.

Finally, the substantial value of energy storage becomes apparent in its potential contribution to shaving NBVC-level monthly demand peaks. Figure 4 shows demand charge savings to NBVC from shaving monthly demand peaks.

Figure 4: Demand Charge Savings to NVBC



2.2.5 Total Savings – Energy and Demand – PV + energy storage

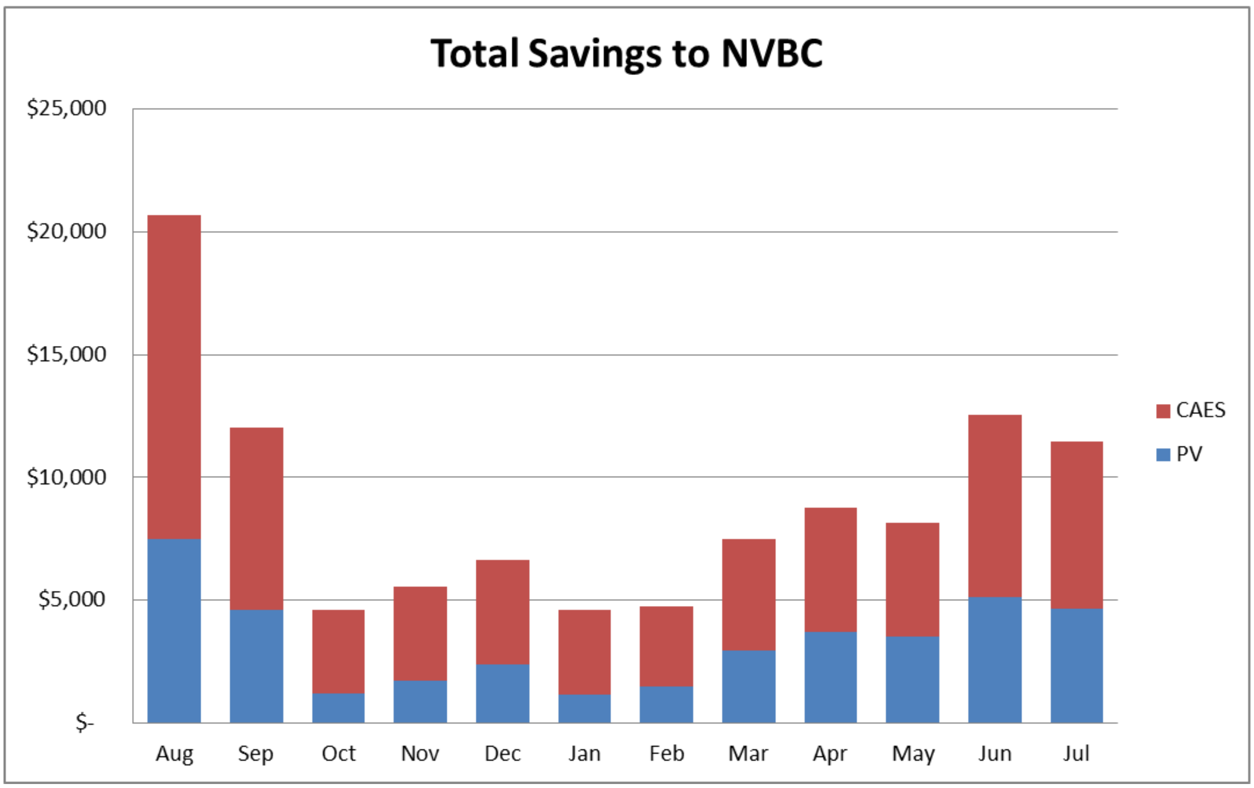
Table 2 shows total savings to the NBVC from the energy and demand charge reductions previously discussed. Full deployment of the PV plus energy storage project at the MUSE would have resulted in over $107,000 in savings to the NBVC during the measurement period. Given that the project was designed to serve the MUSE facility loads, which itself represents only 2% of overall NBVC loads, this is a strong result.

Table 2: Combined Savings to NBVC

Savings		Average Month	Annual
Energy (kWh)	PV	$ 1,583	$ 18,996
	Energy Storage	$ 237	$ 2,843
	Combined	$ 1,820	$ 21,840
Demand (kW)	PV	$ 1,759	$ 21,112
	Energy Storage	$ 5,361	$ 64,334
	Combined	$ 7,121	$ 85,447
Combined (Energy + Demand)		$ 8,941	$ 107,286

Figure 5 shows the same total savings to MUSE in graphical form, with savings per month and relative contributions between PV and energy storage highlighted.

Figure 5: Total Savings to NVBC



It is important to note this analysis is completed on a system that is undersized in PV, and oversized on energy storage, given the magnitude of the MUSE facility loads. Both the PV generation and energy storage components were dramatically undersized compared to overall NBVC loads. A much larger PV and energy storage system deployed at NBVC level could show significantly higher cost savings, in the range of 20% to 40%, while contributing to substantially to energy security on the base.

Financial and payback analysis for the project can be found in the Resilience Mode section of the MUSE facility Study in Appendix A.

CHAPTER 3: Project Engineering, Design and Integration

This chapter details the engineering, design and integration of the project microgrid system. Foresight Renewable Solutions (FRS) worked with U.S. Naval Facilities Expeditionary Warfare Center (EXWC) and Pacific Data Electric (PDE) engineers to detail equipment and component selection, which was to include:

- Battery Energy Storage System (BESS), with round trip efficiency to 75% or higher.
- Power Electronics: For power conditioning and grid-tie capability.
- MicroGrid Interconnection/Interface.
- PV Generation: Up to 150kWs of state-of-the-art solar PV modules plus collection system components, inverters, transformers, and interconnection switch-gear appropriate for a utility grade installation.

FRS worked with PDE and Belco to finalize racking designs for the solar PV component of the demonstration project. Furthermore, PDE was to prepare stamped project layouts, construction drawings, and one-line diagrams for the demonstration project.

The project system, as installed, was comprised of two Imergy ESP30 vanadium-redox flow battery units, two solar arrays (one rated at 24kW, the other 18kW), a diesel generator, and the Geli Energy Operating System (EOS) microgrid controller. As is explained below, no net metering or utility approvals were required, as the project system was built without a grid interconnection.

3.1.1 Engineering Design and Layouts

As previously mentioned, the Navy's MTB project fell dramatically behind schedule and was not deployed during the term of the project grant. As the MTB project was to provide this project's utility grid intertie as well as the intertie with the MUSE facility distribution feeder and all related loads, the project team was forced to find alternate means to test their system. Instead of having a grid tie at the MUSE facility and being tied to building 1360 on the MUSE facility premises to act as the load, this project had to be a stand-alone system with no direct tie to the grid or to load. As a result, the system needed elements to form the grid and to act as the load as well as the other elements of a standard microgrid. The project system originally comprised three Imergy ESP30 vanadium-redox flow battery units rated at 35 kW/140kWh each using MLT Powerstar inverters, two solar arrays (one rated at 24 kW, the other 18 kW) with Renesola Series 156 - 300W panels and two Ingecon solar inverters, a Doosan 100 kW portable diesel generator (rental), an Avtron 20 kW load bank, and the Geli Energy Operating System and microgrid controller.

The initial solution was to re-purpose the available project assets to serve both grid and load as shown in Figures 6-8. ESP30-1 was to form the grid, ESP30-2 was to act as the true battery in the system and ESP30-3 was to act as the load. The diesel generator was originally intended to offer black start support and back-up power as needed. As the project progressed it became apparent that ESP30-1 was not powerful enough to act as the grid-forming element so the diesel generator was employed to serve in that role.

Figure 6: Imergy Block Diagram of original Microgrid System

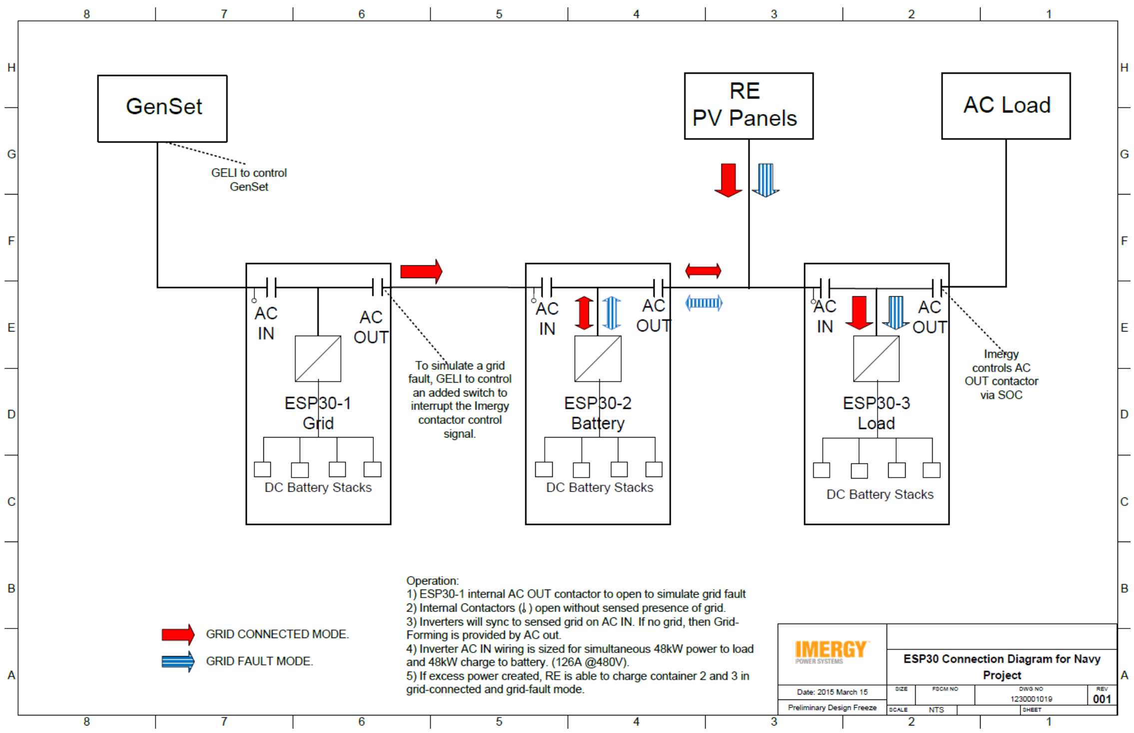


Figure 7: Project Single Line Diagram

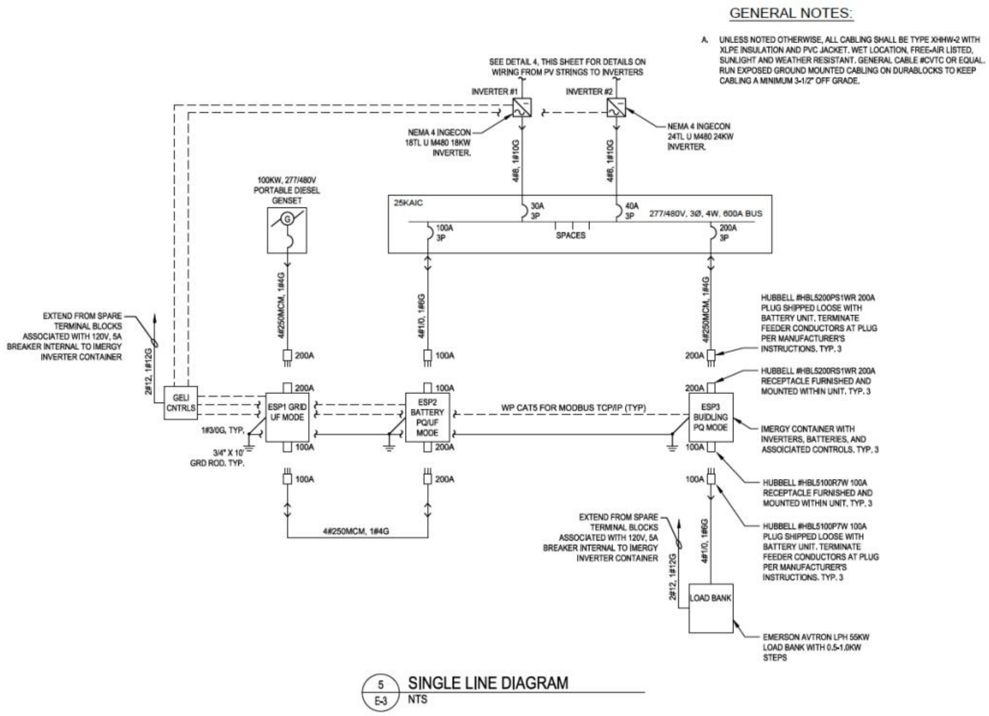
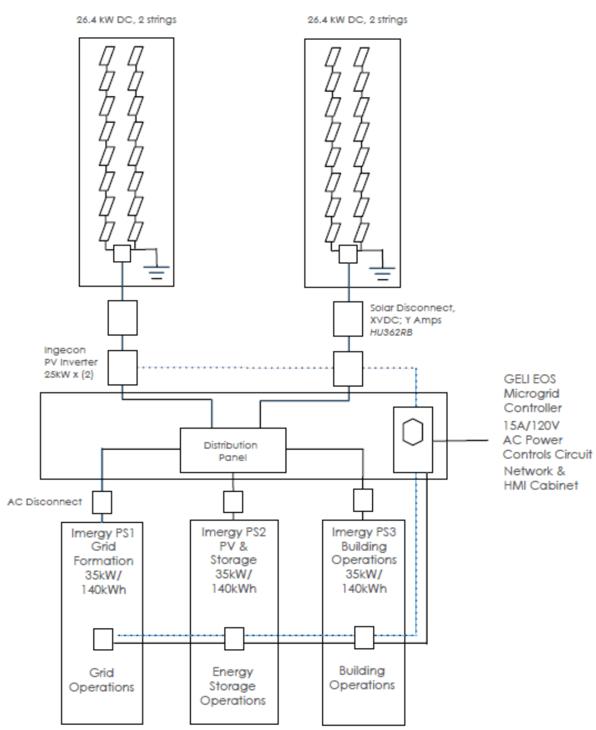
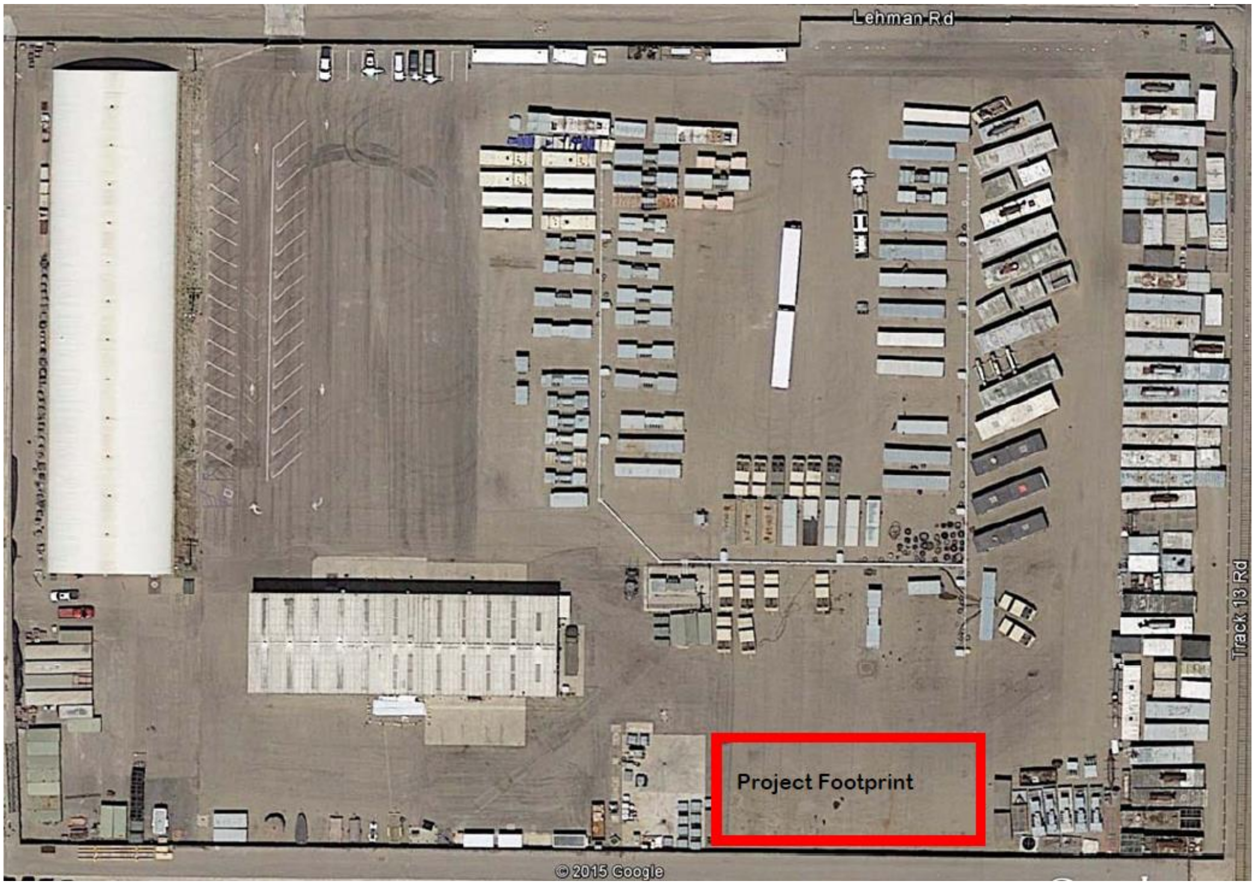


Figure 8: Geli's microgrid communications diagram



The project was installed at the MUSE (Mobile Utilities Support Equipment) facility located at the Naval Base Ventura County in Port Hueneme, California. Figure 9 shows an aerial image of the site prior to construction.

Figure 9: Aerial View of MUSE Facility and Project Footprint Before Construction



The as-built diagram from PDE Total Energy Solutions layout of the equipment in the project footprint is shown in Figure 10. A zoomed in view of this same area is shown is shown in Figure 11 and Figure 12 shows the physical wiring configuration of the microgrid system.

Figure 10: Electrical As-Built of Microgrid System Within Project Footprint (bottom right)

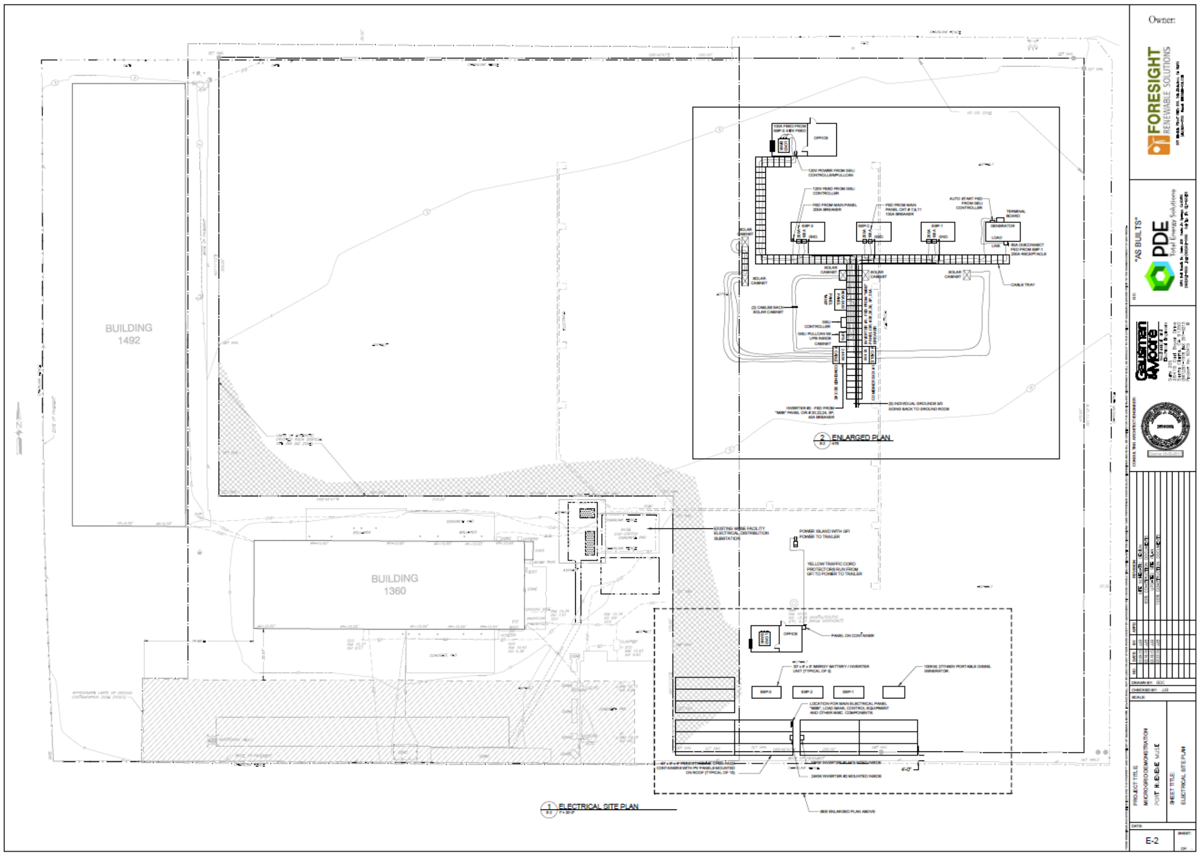


Figure 11: Zoom View from As-Built of Microgrid System in the Project Footprint

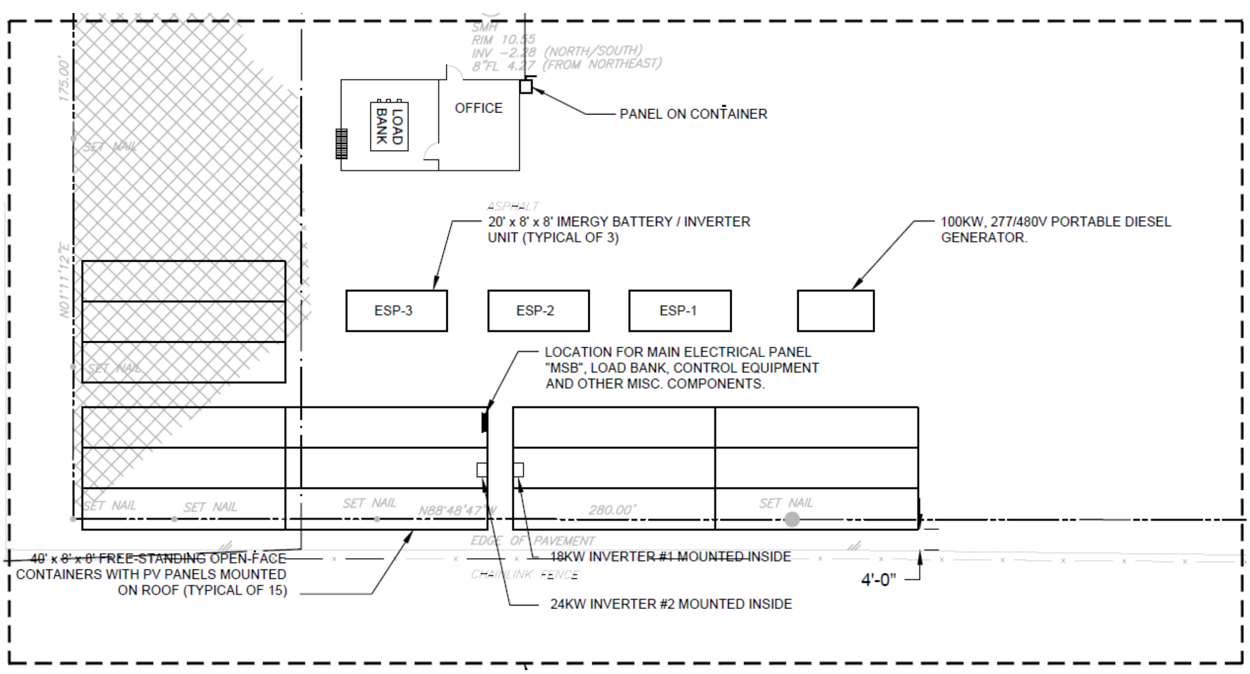
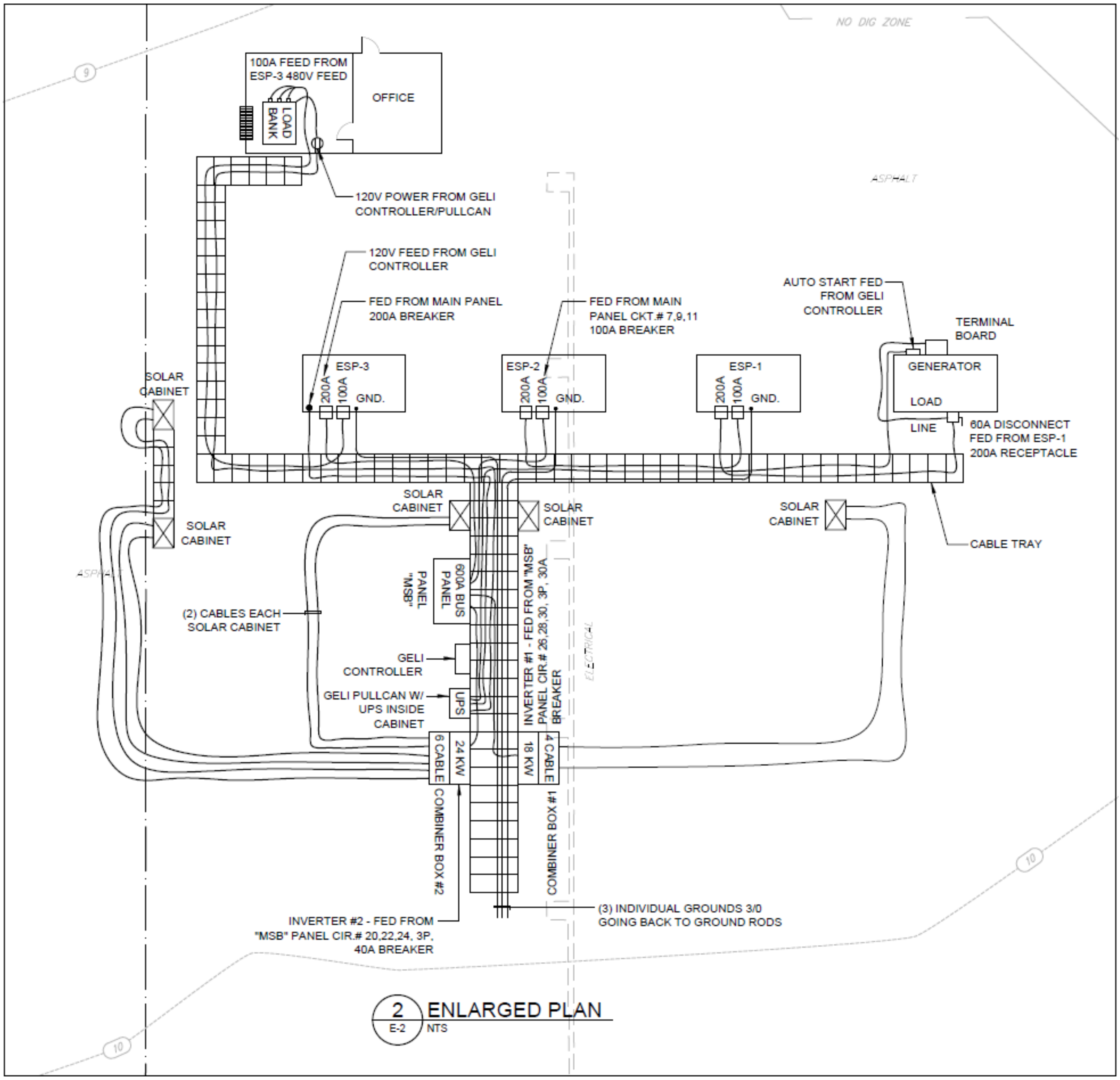
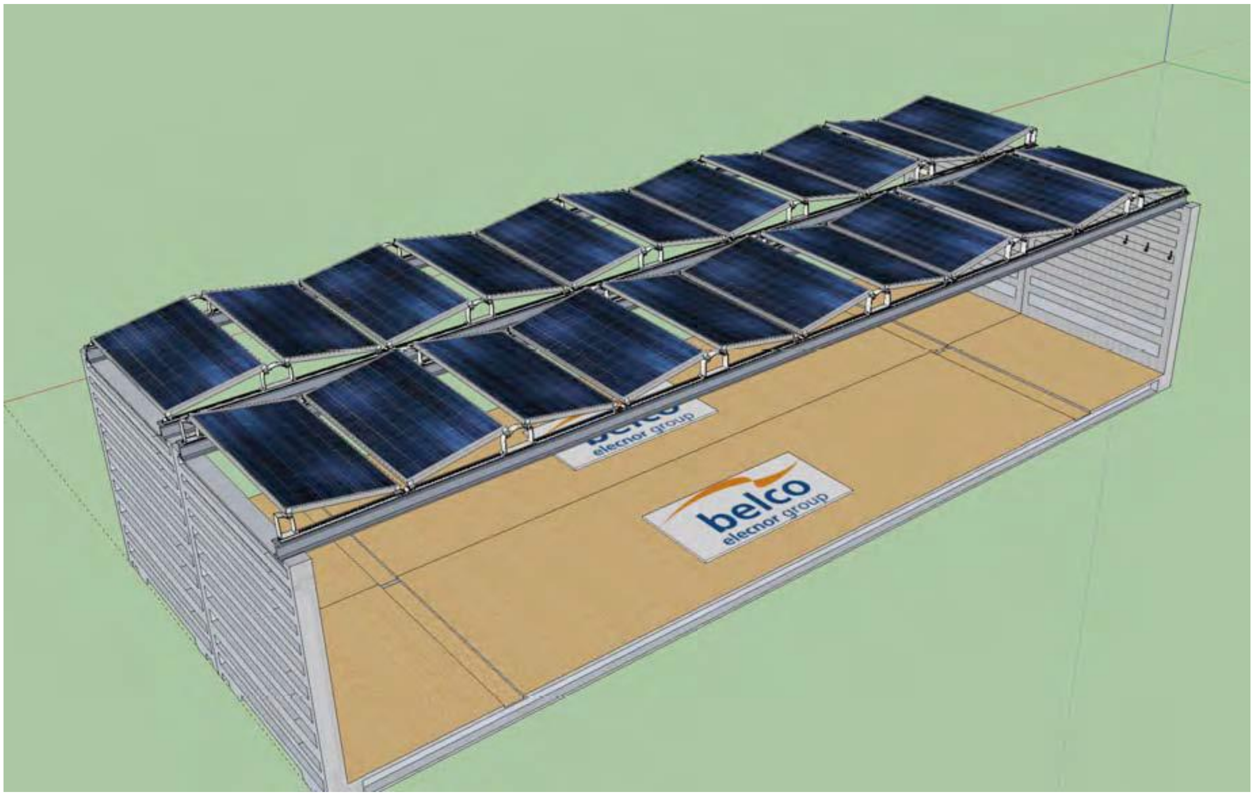


Figure 12: Zoom View from As-Built of Wiring Configuration of the Microgrid System



A requirement for siting the project at the MUSE facility was that no permanent structures were erected. To comply with this Navy requirement, the solar arrays were mounted on open-face shipping containers. Due to physical space constraints the total number of shipping containers that could be used was fifteen (15). To maximize output from this configuration an alternating tilt arrangement was deployed as shown in Figure 13. This allowed for greater output from the arrays vs. all the panels being tilted in the same direction. However, this also limited the installable PV to approximately 50kW, and ultimately closer to 40kW were allowed at the site due to space constraints at the MUSE facility.

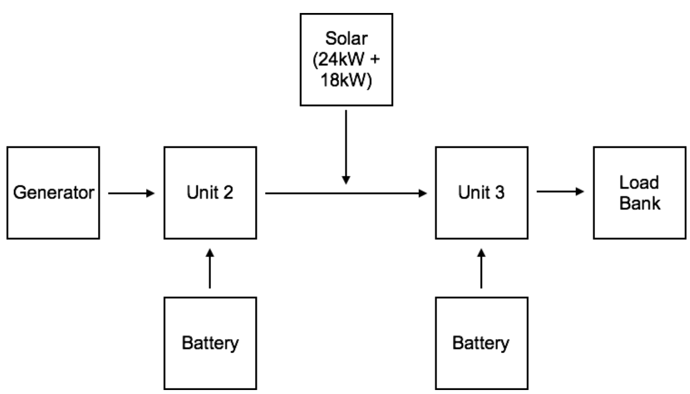
Figure 13: Solar Panel Arrangement on Open Faced Shipping Containers



3.1.2 Final System Block Diagram

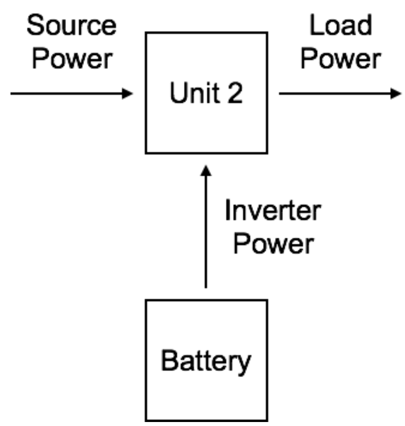
Figure 14 depicts a block diagram for the microgrid system. The power flows are also defined for use in the remainder of the report. Arrows denote the flow of positive power.

Figure 14: System Block Diagram



In this system, the generator functions as a constant power source during limit testing. In all other test cases, the generator simulates the grid. Unit 2 (ESP30–2) functions as the microgrid's energy storage system. Unit 3 (ESP30-3) simulates load by charging from Unit 2. Unit 3 also dispatches power to the load bank as needed to ensure that the unit does not overcharge. In addition, the Geli Microgrid Controller also communicates with each Imergy Unit. The Geli Microgrid Controller records, among other metrics, power flow between each battery unit and the rest of the system. The power flow conventions for Unit 2 and Unit 3 are established in Figure 15.

Figure 15: Imergy Unit Block Diagram



Arrows denote positive power flow. In summary, Source Power is incoming power to the unit, Inverter Power is the actual AC power entering/exiting the battery, and Load Power is dispatched power from the unit. All power flows are in AC power unless otherwise stated. Note that in addition to directly measuring solar power output, solar power appears in the Load Power of Unit 2 as negative power. Therefore, solar power can also be inferred from the Imergy unit outputs as the difference between Load Power, Unit 2 and the power reaching Unit 3 (Source Power, Unit 3).

3.1.3 System Component Summary Table

Table 3 summarizes the system components (part of the "final equipment list") and their uses within the system under the different testing conditions, as well as how they are measured through the Geli EOS interface.

Table 3: System Component Summary

Component	Size	Usage During Limit Testing	Usage During Microgrid/Other Testing	Measured Via
Solar PV Array	24kW + 18kW	Not Used	Solar Power Source	EITHER Solar Power OR (Source Power, Unit 3 – Load Power, Unit 2)
Unit 2	35kW/140kWh	Battery	Energy Storage	Inverter Power, Unit 2
Unit 3	35kW/140kWh	Battery/Load	Load	Source Power, Unit 3
Generator	100kW	Constant Power Source	Grid/External Power	Source Power, Unit 2

CHAPTER 4: Project Implementation, Construction and Commissioning

Project participants, led by Foresight Renewable Solutions (FRS), were charged with managing the construction and complete the commissioning of the demonstration project.

FRS also completed the following tasks:

- Work with Pacific data Electric (PDE) and U.S. Naval Facilities Expeditionary Warfare Center (EXWC) to manage the delivery and laydown of all equipment.
- Manage the PDE's civil construction works, which are primarily the installation and bolting down of the BESS units and interconnection piping, as well as the racking solution (open faced storage containers) for the PV modules.
- Manage PDE and Belco's electrical works, primarily the reinforcement of the microgrid, installation of necessary circuit breakers, installation of power controls, and installation of the PV system.
- Work with PDE, EXWC, and BESS manufacturer on the commissioning of the demonstration project and initiation of operations.

4.1 Project Development

As is outlined in the project development timeline, a number of substantial challenges emerged during the development of the project that required FRS to be extremely adaptive managing the Grant to completion:

- Grant awarded to FRS – May 2013
- Navy's MTB project schedule determined to be well behind this project's schedule which meant they could no longer happen in conjunction as planned – Jan. 2014
- Compressed Air Energy Storage (CAES) solution from LightSail determined to not be able to meet project schedule due to set back with alpha testing – April 2014
- Investigation begins to replace CAES – May 2014
- Imergy vanadium redox flow battery proposed as replacement for CAES – May 2014
- Energy Commission approves removal of CAES technology and inclusion of Imergy technology as well as PDE as the project general contractor and Geli as the supplier of the software controls – June 2014
- Executed agreement with Navy for project to be sited at the MUSE facility at Naval Base Ventura County – Jan. 2015
- MUSE facility approved final system layout – March 2015

- Installation of microgrid system commenced – May 2015
- Electrolyte safety training conducted by Imergy with Navy – May 2015
- Installation of equipment completed – June 2015
- Testing – Jan. 2016
- System decommissioned – Feb. 2016

The original microgrid system to be funded by this grant award was to include 250 kW/ 1000 kWh of Compressed Air Energy Storage (from LightSail Energy, Berkeley, California) and 75 kW of solar PV panels and accompanying balance of system components. This grant-funded equipment was to be integrated with a broader microgrid project that was planned by the Navy at their Expeditionary Warfare Center's Mobile Utilities Support and Equipment Facility at the Naval Base Ventura County at Port Hueneme, California. This broader project, called Microgrid Test Bed (MTB) was to include 250 kW/500kWh of lithium ion batteries and an additional 75 kW of solar photo voltaic panels and accompanying balance of system components and would include an on-site grid tied interconnection to their local substation and connectivity to a building on the site known as Building 1360, as well as a 250kW diesel back-up generation set. The Navy's goals for their broader MTB project were in line with the goals of this grant-funded project which created the opportunity for the Navy to have access to an expanded microgrid system that included multiple energy storage technologies and for the project to have a hosting location that would be ideal for proving out the concepts outlined in the original grant proposal.

Once the grant was awarded and project planning got underway, two things became apparent that would alter the course of the project. The first, fully one year into two year grant schedule and project planning and development, it became evident that the proposed CAES technology by LightSail was not going to be ready in time to work with the project timelines. The second was the fact that the Navy's broader MTB project's schedule was not going to line up with the project schedule due to delays for various reasons.

To solve the first issue, FRS immediately set out to find a technology and technology provider(s) that could serve as a best fit substitute for achieving the goals and objectives of this research. FRS selected flow battery technology as the best fit for the project. A flow battery is a type of liquid electrolyte battery with properties that allow storage capacity to be easily expanded by adding more electrolyte holding capacity without increasing the power output capacity, a property it shares with CAES. The particular chemistry selected for the flow battery was the vanadium redox flow (VRF) battery technology from Imergy Power Systems of Fremont, California. At the same time, Growing Energy Labs, Inc., San Francisco was selected to develop controls for integrating the new storage system into the microgrid.

To solve MTB delay issue, the project team had to be creative in redesigning and deploying the project system which was finally comprised of three Imergy ESP30 vanadium-redox flow battery units rated at 35 kW/140kWh each using MLT Powerstar inverters, two solar arrays (each 25kW, although ultimately one rated at 24 kW and the other rated 18 kW were installed given space constraints at the MUSE facility) with Renesola Series 156 - 300W panels and two Ingecon solar inverters, a Doosan 100 kW portable diesel generator (rental), an Avtron 20 kW load bank, and the Geli Energy Operating System and microgrid controller.

Instead of having a grid tie at the MUSE facility and being tied to Building 1360 to act as the load, this project had to become a stand-alone system with no direct tie to the grid or to load. As a result, the stand-alone system needed elements to form the grid and to act as the load as well as the other elements of a standard microgrid. The final setup is described in Chapter 3.

4.2 Construction & Commissioning

Project installation began May 4, 2015, and was completed August 31, 2015. The bulk of the installation was completed by June 30, 2015, including all the equipment for the microgrid system (open-faced shipping containers, solar racking and panels, batteries, software controls console, wiring, etc.). July and August activities were primarily fine-tuning and troubleshooting various aspects of the microgrid system. Given the complexity of the system, there were many minor details to be ironed out by the project team in order to complete the installation.

FRS served as prime for Prime for this project, including the conceptualization and preliminary design for several iterations of the project. Importantly, FRS also managed the installation and decommissioning of the system, insuring that all individuals had base access by getting the base security office all requisite information with adequate lead times.

PDE was the General Contractor and Belco Electric was PDE’s electrical subcontractor for the installation. PDE was responsible for doing the final electrical & construction design for the system, and with FRS, getting it approved by the Navy. For the installation PDE worked with FRS in coordinating the shipping of all materials and equipment to the site. PDE was responsible for the physical laydown of all equipment within the project footprint, among many other things like running Ethernet cables from each device to the web relay cabinet. Belco was responsible for installing the solar on top of the open-faced shipping containers and doing all the wiring for the entire system. PDE also performed the system decommissioning activities.

Imergy Power Systems was responsible for the installation and integration of their battery units into the microgrid system. The battery units were shipped empty of electrolyte so one of the activities that Imergy managed initially was the delivery of the electrolyte and the pumping of the electrolyte into the three Imergy battery units. Once that was completed, the units were ready to be tested. Given that this was the first time this technology has been deployed in the field at this scale, several issues arose regarding the functionality of the units. Some issues were hardware related and others were software related. Imergy systematically worked through all the issues over the course of July and August. Needless to say, this several month delay hurt the project schedule, ultimately dramatically limiting the time we had to conduct testing activities.

Growing Energy Labs, Inc. (Geli) was responsible for integrating their energy controls software designed to manage the functionality of the entire microgrid system (PDE and Belco did the physical installation of the Geli software console at the site). Geli was instrumental in conducting the project-testing plan, gathering data and writing the final report to the Energy Commission.

Imergy's choice of inverter from a South African company prolonged the commissioning and troubleshooting phase of the project, resulting in additional delays. The team chose the inverter thinking it was the best solution for the somewhat unorthodox redesigned project architecture. However, it turned out this choice led to extensive remote and onsite troubleshooting by both Imergy and Geli that used up the time allotted by the Navy for project operation at the MUSE facility. The project was to have completed its testing and to have removed all the equipment from the site by the end of 2015. This date also coincided with the end of the grant-funding period. These and other commissioning and troubleshooting milestones are summarized in Table 4.

The Navy granted FRS and team an extension until February 28, 2016 to complete testing and remove equipment from the Navy base. This extension fell outside the Energy Commission grant term, and was therefore self-funded by the project team (FRS, PDE, Geli, Imergy).The team worked intensively and successfully in early 2016 to stabilize the system, commence testing and achieve the testing results documented.

Table 4: Imergy's Addressing of Technical Issues

Week	Issues Highlight or Milestone
June 15 – June 22	Learned that Imergy overlooked the low voltage charge specifications for MLT inverters which are not suited to perform a low voltage pre-charge of the system. Damaged two inverters in the process. Imergy returned the following week with replacement modules for repair and alternate pre-charge equipment.
July 20	Operational data helped identify a faulty stack (System #3). Imergy isolated the stack and configured the system to operate at reduced capacity temporarily. New stack build requested.
Jul 27 – Sept 14	Addressed a range of operational issues including tuning, stability of generator synchronization, master/slave coordination and system start-up integration.
Aug 24	Finished resolution of major remote control interface bugs and performed remote testing validation with Geli operator of functions (except for power dispatch).
Aug 31	Performed physical repairs on 3 MLT inverters IGBT failures caused by control stability issues. Performed project reconfiguration to address microgrid design problem with power flow and interplay between many inverters.
Aug 31	Replaced faulty stack from System #3 and returned it to HQ for inspection. Identified manufacturing error as source of problem.
Sept 14	Resolved power dispatch control algorithm and bugs. This was the final piece to complete the remote control functionality requirements of the ESP30s. It became clear early in this project that the MLT inverters power control functionality was not suited to the application requirements and required a custom control algorithm overlaid by the Imergy controller. This added a significant amount of development effort from Aug-Sept.
Sept 14	Overcame remaining handful of operational bugs of MLT inverters. Arranged for MLT engineer to travel from South Africa to Imergy office and provide a dedicated week of

Week	Issues Highlight or Milestone
	real-time support.
Sept 14	Replaced a stack in System #2. It had previously been found to have a small leak due to installation handling damage. This did not affect the performance of the system.
Oct 2	Did final remote control demonstration and hand-over to Geli operator.
Oct 26	Imergy travelled to site to repair a further inverter IGBT failure
Nov 30 – Dec 14	Performed new studies of both flow and heat management of the systems to validate models and enhance understanding of operational characteristics. This was done outside of the core project demonstration goals.

Figures 16-21 show selected images of the equipment installed at the MUSE.

Figure 16: Solar Panel Installation on Open Faced Shipping Containers with I-Beams

Figure 17: Imergy Batteries with Tubs Full of Electrolyte

Figure 18: Shipping Containers with I-Beams Supporting Solar Panels – A New Design Created for this Application

Figure 19: Imergy Batteries with Electrolyte Loaded and Ready to Accept Charging from the Solar System and Diesel Generator

Figure 20: The Fully Assembled Electrical Components of One of the Imergy Batteries

Figure 21: Parties from PDE, Geli and Imergy discussing the commissioning process

CHAPTER 5: Operation, Data Collection, & Analysis

5.1 Data Collection Test Plan

The project goals in the Commissioning and Test Plan are to successfully confirm full system operations, as well as perform a series of tests that simulate different operating modes of the system. These are:

1. *Limit testing*. Charging at rates of 35kW, 30kW, 20kW, 10kW, and 5kW, and discharging at the same rates; charging from solar at minimum and maximum charging rates; measuring solar array performance; charge/discharge cycles at 30kW/30kW and 10kW/10kW; calculating energy storage, power converter, and system efficiencies.
2. *Performance Testing*. Operating the Demand Charge Management (DCM) Energy App; operating the Microgrid Operations Energy App and demonstration of 24-hour continuous operation in islanding mode; operating the Renewable Integration and Firming Energy App under solar intermittency.

5.1.1 Limit Testing Plan

- Power test each Imergy Power System charging at maximum power of 35kW. Use generator to charge Imergy Power System units.
- Repeat for charging power of 30kW, 20kW, 10kW, and 5kW
- Power test each Imergy Power System discharging at maximum power of 35kW.
- Repeat for discharging power of 30kW, 20kW, 10kW, and 5kW
- Perform maximum charging power test from solar PV array at lower voltage limit and upper voltage limit of Imergy Power System units.
- Measure performance of solar PV arrays and inverters by collecting one day of generation data. Collect DC Voltage, DC current, AC Voltage, AC current, and phase.
- Perform minimum charging power test from solar at low voltage limit and upper voltage limit of Imergy Power System units.
- Calculate energy storage, power converter, and system efficiencies from energy capacity tests.

5.1.2 Performance Testing Plan

There were two primary modes of operation intended for the microgrid system: Microgrid/ Island Mode and Grid Connected Mode. Grid Connected Mode - Demand Charge Management Testing Plan

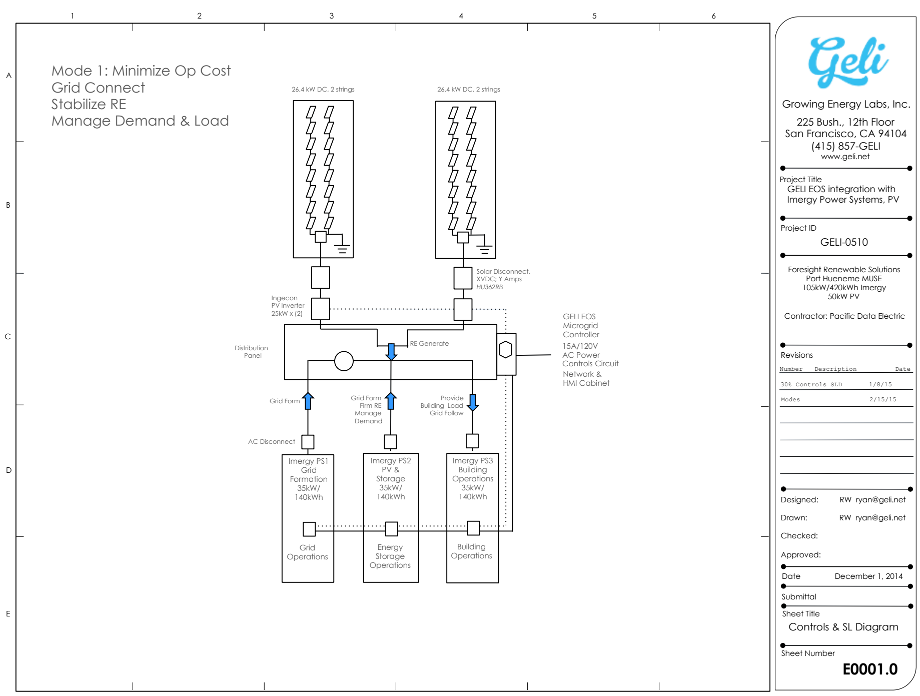
Grid Connected Mode is when the system is connected to the overall electrical grid, which in this case was simulated using the 100 kW diesel generator. The system owner would not rely on the microgrid system for survivability. Instead, in Grid Connected Mode, the system can perform functions that will have economic benefit to the system owner. For this project, the economic benefit tested was Demand Charge Management. Utility energy billing in some utility territories is not solely based on overall energy consumed. In certain utility territories, especially for commercial or industrial customers, there is also a demand charge component to energy billing. This charge is associated with peaks in demand from the customer as these peaks cause stress to the grid and therefore the utility must be compensated for this stress since it results in greater maintenance and shorter lifespan of the grid equipment. Demand Charge Management is the process whereby energy stored in the batteries is released to serve the local load at times when peaks are happening in order to reduce these peaks from the utility/grid perspective. In situations where the system owner has significant peak demand occurrences and when Demand Charge Management is functioning properly, the savings can be significant.

5.1.2.1 Demand Charge Management Testing:

- The Geli EOS Demand Charge Management Energy App was run to provide automated demand charge management. Imergy Power System Unit 3 was programmed with a load profile equivalent and proportional to the MUSE facility. Imergy Power System Unit 3 (facility) pulled load from the grid (Imergy Power System Unit 1) while Imergy Power System Unit 2 (storage unit) charged or discharged in response to automated power controls incorporating optimization algorithms to reduce the economic cost of the demand charge (Figure 22).

- The performance of the Demand Charge Management Energy App was compared to the pre-calculated analytic model and the accuracy of the Geli EOS DCM Energy App.

Figure 22: Demand Charge Management Power Flow Diagram



5.1.2.2 Demand Charge Management Testing:

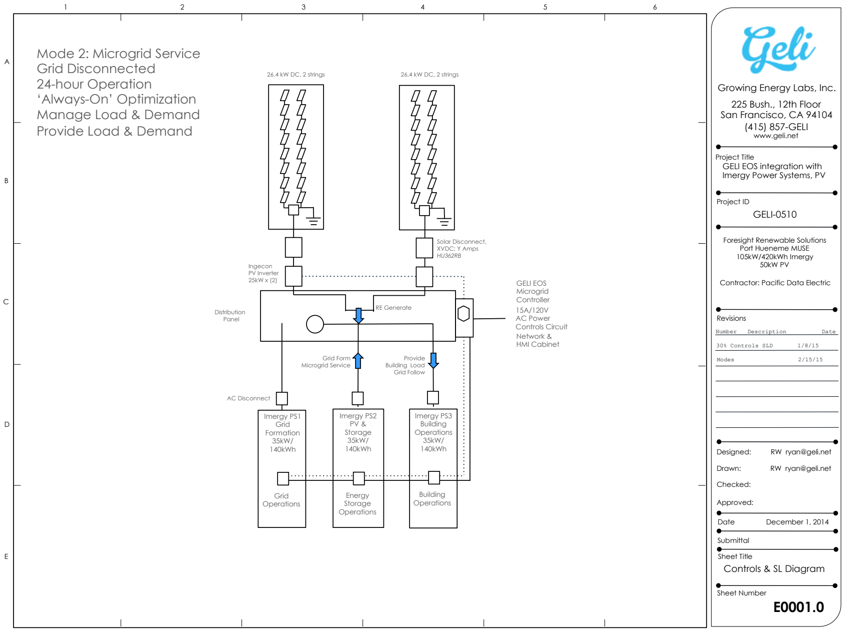
Island Mode is when the system is not connected to the grid and truly acts as a microgrid. For the Navy, this functionality is of significant interest for military bases abroad, including forward operating bases in hostile territory, as well as for all their stateside bases. It is a military imperative for any base to be able to stand on its own and to be operational regardless of the external conditions. Reliance on the grid for stateside or permanent bases abroad creates a weakness that can be exploited and thus presents one of the biggest vulnerabilities present at any given base. For forward operating bases that are temporary in nature, the energy generation is almost entirely fossil fuel-based (mostly diesel). This reliance on fossil fuels can only be met with shipping supply lines that are vulnerable to enemy attack. Less reliance on supply lines makes a base more resilient, as it does not depend on deliveries of fuel to power itself. It also reduces the expense – most importantly for human casualties and also the tremendous monetary cost of defending and maintaining supply lines.

A properly designed microgrid that has renewable generation and battery storage in the mix creates a situation of extended and potentially indefinite survivability for a base where the microgrid is deployed. Diesel generators or high power-density batteries will always need to be in the mix of any microgrid to operate effectively in Island Mode for things like black start, grid forming and auxiliary generation when other renewable generation options are temporarily not available. However, a properly designed microgrid will utilize diesel generators very little, if at all. The primary source of renewable energy for a microgrid is often solar PV. However, small wind can be employed as well. For this project, solar PV was used in conjunction with energy storage to prove out the islanding capability of a microgrid system with those elements.

5.1.2.3 Microgrid/Island Mode Testing:

- Simulate grid loss and confirm system disconnection and reconnection after grid returns according to UL1741.
- Demonstrate continuous 24-hour operation in microgrid mode where GELI EOS services facility load based upon daytime PV energy generation and nighttime discharge of energy from the batteries. Figure 23 schematically illustrates Islanded Mode operation.

Figure 23: Microgrid/Island Mode Power Flow Diagram



5.2 Data Collection & Analysis

This section analyzes data collected by the Geli EOS during the operation of the system by the Geli EOS.

Task 5 of the Statement of Work ("Project Operation, Data Collection, and Data Analysis") includes provisions for collecting six months of data and analyzing the outputs of this data. This includes:

- Daily and average kWh of solar PV production per day; and percentage of the solar PV production that supplies the microgrid directly and charges storage
- Net capacity factor of solar PV and net kW capacity
- Daily and average BESS charging in kW and kWh (Charging will be broken down by source, e.g. solar, grid, diesel back-up, etc.)
- Daily and average BESS generation in kWh (include the daily and average kW loads)
- Round trip efficiency (percentage) of BESS across various charging / discharging capacities (kW) and sources of charging
- Average operational availability of solar PV and BESS

Due to difficulties in both system hardware integration and software integration with the Imergy Power System units, the Geli EOS was unable to monitor and control the system for the full six months of data. In particular, only one day was allotted for DCM testing, which did not allow for full troubleshooting and configuration of the algorithm, which takes, at a minimum, several days to verify its capabilities. However, Geli was able to perform several commissioning tests during the short operational time of the system. The outputs of testing performed are presented below.

Datasets of the Port Hueneme system were obtained through the Geli EOS interface. The datasets comprise of data taken at 1-second intervals for the entire system across the testing period. The data includes voltage, power, state of charge (SOC), and other important metrics. Note all figures show AC power flow unless otherwise stated.

5.2.1 Limit Testing

Limit testing is defined by a series of charge and discharge cycles of the Imergy Power System Unit 2 at constant power. This is important for both testing the power conversion efficiency of the Imergy Power System units, but also for testing Geli's capability to command and control the system using the EOS. While Geli's original commissioning plan included charge and discharge limit testing cycles at a variety of constant power, due to limitations of the integration with the Imergy Power System units, a subset of the limit tests was performed by Geli.

During charging, Unit 2 is supplied with constant power from the generator. During discharging, Unit 2 discharges at a constant power to charge Unit 3. The effective charge limits are defined by Imergy as 15% SOC - 75% SOC, with a small allowance for overage on both ends. Two charge/discharge tests were performed and the data is presented below. Round-trip efficiencies, as well as power conversion efficiencies, are also computed.

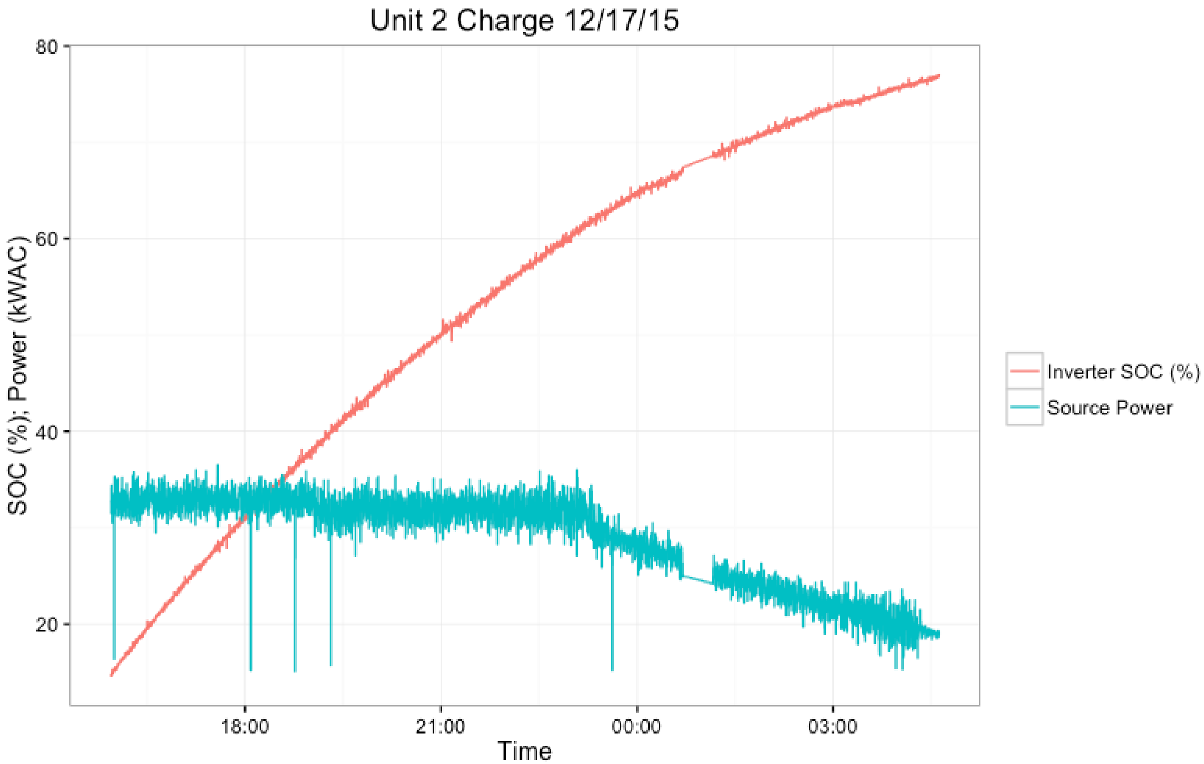
5.2.1.1 30 kW Charge/30kW Discharge

The charge and discharge of this test took place over two separate days (12/16/15 and 12/22/15). Unit 2 was intended to be charged at 30 kW and then discharged at 30 kW.

5.2.1.2 30 kW Charging Summary

Figure 23 shows the Unit 2 charge that took place overnight from 12/16/15 to 12/17/15.

Figure 23: 30kW Charging, 12/17/15

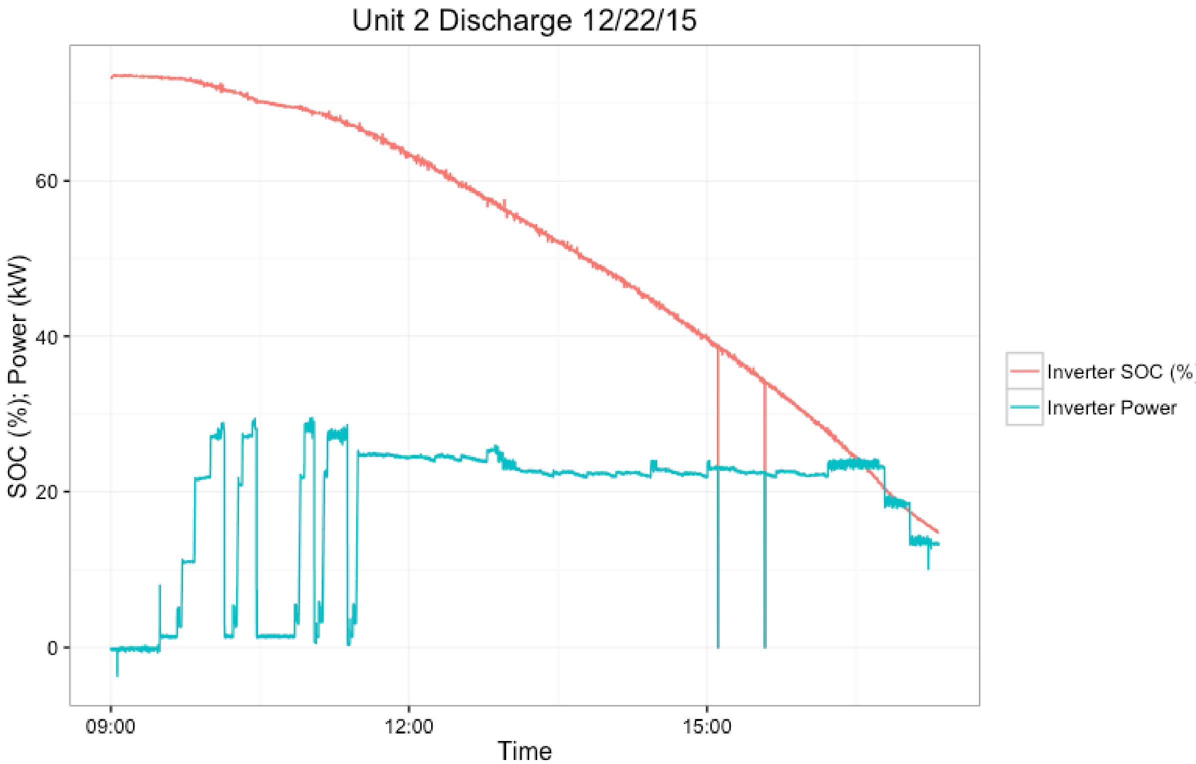


Note that an error in data collection took place from approximately 12:42 am to 1:10 am December 17, 2015 and the missing values have been linearly interpolated. The charge began approximately constant at 30 kW, but automatically linearly decreased at approximately 11 pm to handle operating voltage limits, dipping below 20 kW by the end of the charge cycle. The SOC of Unit 2 increased smoothly from 14.8% to 76.8%.

5.2.1.3 30 kW Discharging Summary

Figure 24 shows the Unit 2 discharge that took place on December 22, 2015.

Figure 24: 30kW Discharging, 12/22/15



The discharge was not at 30 kW, but instead stability issues necessitated a lower value. These early fluctuations represent manual control iterations. A stable discharge between 22-25 kW was achieved for the remainder of the test, followed by a manual step-down in power towards the tail end of the discharge to handle operating voltage limitations. The SOC of Unit 2 decreased from 73.3% to 14.8%.

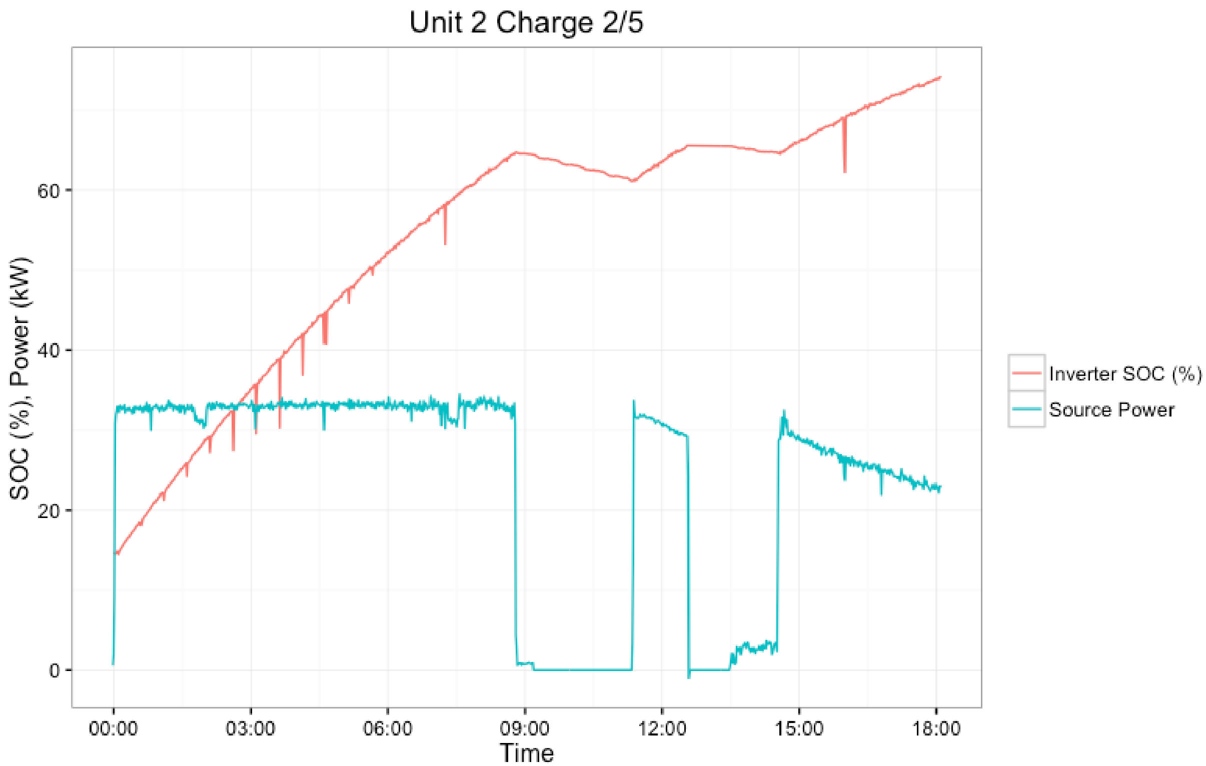
5.2.1.4 30 kW Charge/20 kW Discharge

The charge and discharge of this test took place from midnight 2/5/16 until the early morning of 2/6/16. Unit 2 was intended to be charged at 30 kW and then discharged at 20 kW.

5.2.1.5 30 kW Charging Summary

Figure 25 shows the Unit 2 charge that took place on February 5, 2016.

Figure 25: 30kW Charging, 2/5/16

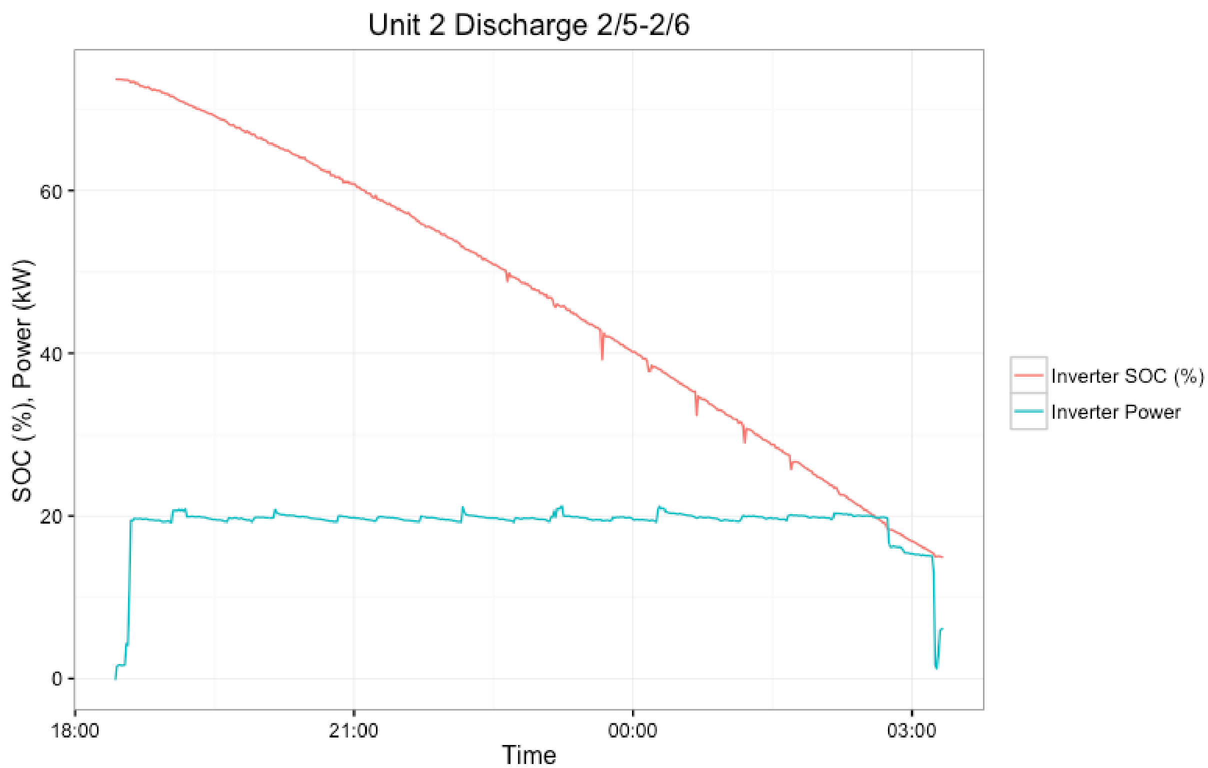


For this test, Unit 2 started at 14.6% SOC. The discharge began relatively constant at 30 kW, though the generator ran out of fuel just before 9am and needed to be refilled. During this time, the battery underwent self-discharge at a rate of 0.6 kW, which resulted in a SOC decrease of 1.46%/hr. The generator was then turned on and charging continued, until Unit 2 unexpectedly shut down from 12:33pm-1:33pm. Charging then resumed at 2 kW then automatically tapered down from 30 kW to handle operating voltage limits, as Unit 2 reached its maximum of 74.1% SOC.

5.2.1.6 20 kW Discharging Summary

Figure 26 shows the Unit 2 discharge that took place from February 5 -6, 2016.

Figure 26: 20 kW Discharging, 2/5/16



The discharge was at a uniform 20 kW, until the discharge rate was stepped down as the discharge ended to handle operating voltage limits. The SOC also decreased from 73.7% to 14.88%.

5.2.1.7 Charging Efficiencies

This section presents efficiencies associated with charging and discharging the Imergy Power System energy storage units. Table 5 defines efficiencies metrics measured for the battery and again for the system.

Table 5: Efficiencies Summary

Name	Purpose	Calculation
Battery DC/DC RTE	Unit 2 Battery DC input to DC output efficiency	Energy exiting battery/ Energy entering battery
Battery AC/AC RTE	Unit 2 Inverter AC input to AC output efficiency	Energy exiting Unit 2 Inverter/ Energy entering Unit 2 Inverter
System AC/AC RTE	System AC input to AC output efficiency	Energy to Unit 3/ Energy entering Unit 2
System DC/AC RTE	Battery DC to/from System AC efficiency	System AC/AC RTE/ Battery DC/DC RTE

Table 6 summarizes the results of these calculations for the 30kW/20kW and the 30kW/30kW charge/discharge cases.

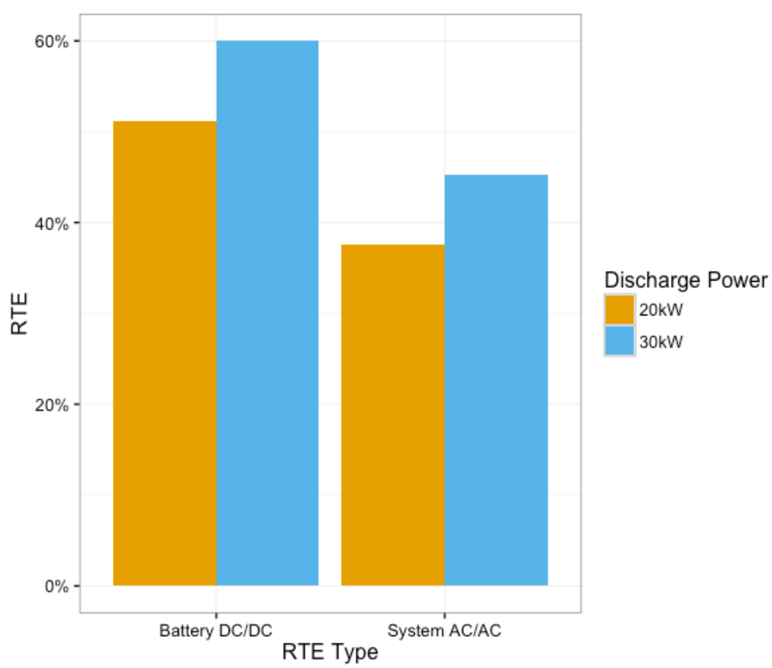
Table 6: Charge/Discharge Efficiencies

Efficiency	30kW/20kW Charge/Discharge	30kW/30kW Charge/Discharge
Battery DC/DC RTE	0.5114	0.6000
Battery AC/AC RTE	0.4560	0.5013
System AC/AC RTE	0.376	0.4529
System DC/AC RTE	0.7348	0.7549

Since the Battery AC/AC RTE takes into account both the inverter DC/AC and AC/DC efficiencies, dividing the Battery AC/AC RTE by the Battery DC/DC RTE yields the inverter RTE for converting power from AC to DC and converting power from DC to AC. Therefore, the round-trip inverter efficiency is 0.8917 for the 30kW/20kW limit test, and 0.8356 for the 30kW/30kW limit test. By assuming that the DC/AC and AC/DC conversion efficiencies are the same, taking the square root of the inverter RTE yields the inverter efficiency. These correspond to average one-way inverter efficiencies of 0.944 for the 30kW discharge and 0.914 for the 20kW discharge.

In addition, system inefficiencies due to other ancillary loads also contribute to efficiency losses between the battery DC power and system AC power. Figure 27 summarizes these efficiencies.

Figure 27: Battery DC/DC RTE and System AC/AC RTE Comparison



The efficiencies are higher for the 30kW discharge than the 20kW discharge. This suggests that on the battery DC side; there is a constant ancillary loss, independent of discharge rate. This comprises a larger percentage of the 20kW discharge power, resulting in lower DC and AC efficiencies. In addition, the AC/AC RTE for both are reduced to 73.48% and 75.49% of the DC/DC RTE for the 20kW and 30kW discharges, respectively. This suggests that both reductions in ancillary loads, as well as improvements in inverter and DC efficiencies, could result in AC/AC round-trip efficiencies of well above 60%.

5.2.1.8 Conclusions of Limit Testing Program

Geli successfully controlled the charge and discharge of the Imergy Power System units to perform constant power charge and discharge limit tests, using the capabilities of the EOS. While the round-trip efficiencies of the system were quite poor, improvements to the battery inverter and reduction of the parasitic ancillary loads of the inverter and battery will improve this round-trip efficiency.

5.2.2 Microgrid Testing

A system with microgrid capabilities uses energy storage to supply uninterrupted power to a load under an unreliable or absent grid. The Geli Microgrid Operations Energy App is deployed for this purpose, and tested under different microgrid scenarios. This functionality is essential for a system that is designed to island during grid outages and continues to operate independently of the grid. Islanded operation is of great interest for the security and dependability of power for the NBVC as well as to a broad range of communities and private and government facilities across California. This testing was used to validate the performance and efficacy of the Geli EOS via the Microgrid Operations Energy App, so that this Energy App can be improved and utilized in future systems.

5.2.2.1 Test Summary

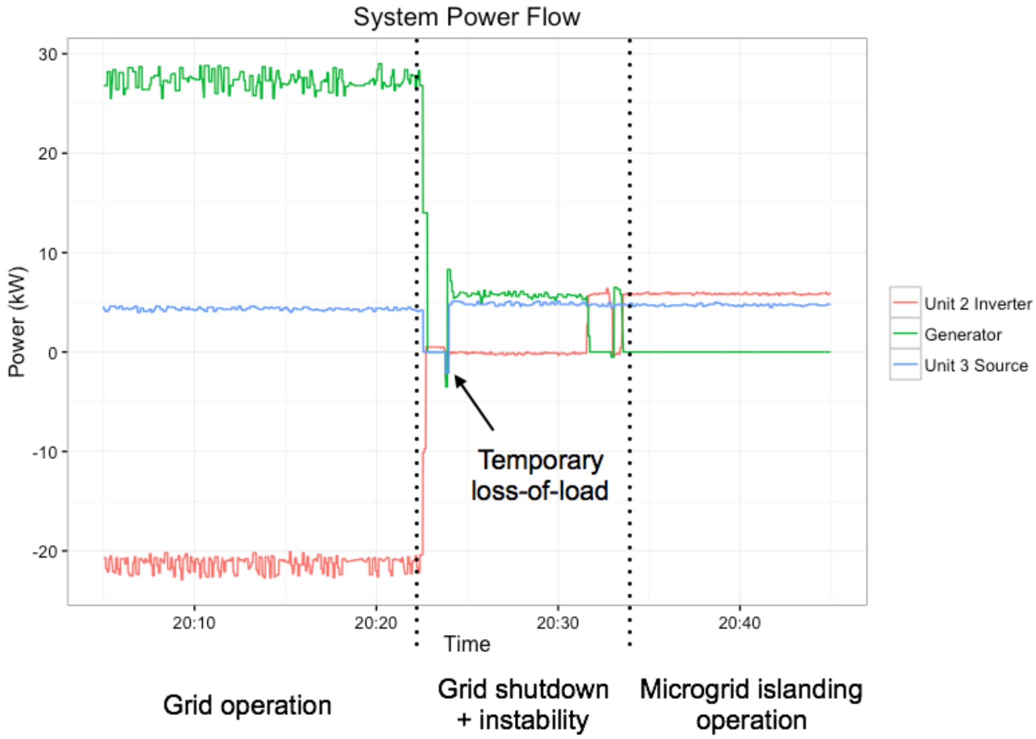
This section presents two different scenarios for testing the microgrid. The first scenario anticipates loss of grid power when it is the primary source of energy, leaving the energy storage system to maintain uninterrupted power to the load. This scenario also includes the capability of the microgrid system to handle the unregulated return of grid power, again using energy storage to maintain uninterrupted power to the load. The second scenario investigates how the system operates in an off-grid, islanding scenario, providing power to the load by managing the deployment and storage of solar PV energy.

5.2.2.2 Grid Intermittency/Outage

In this first scenario, the energy storage system must compensate for the intermittency of power from the grid to keep the load uninterrupted.

Figure 28 shows the power flow of the system on the day of January 15. 2016 on a simulated grid shutdown, where the grid is unable to supply power to the system.

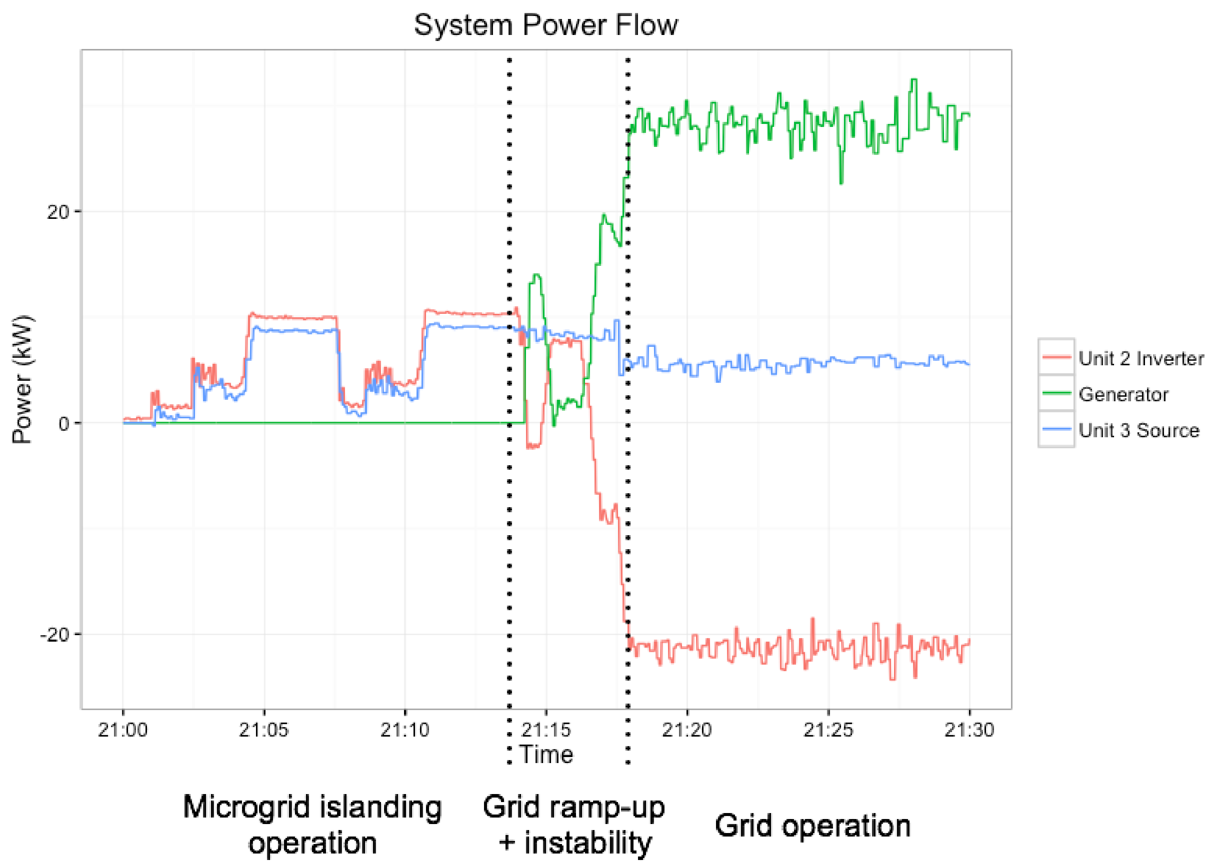
Figure 28: Microgrid System Power Flow, 1/15/16



Unit 2 acts as a buffer from the generator production; overproduction is stored to keeping the load power (Unit 3 Source) constant. When the generator power becomes unstable and eventually shuts down, there is a momentary loss of power to the load, but when the generator is fully shut down and producing no power, the battery dispatches the necessary power to the load.

Figure 29 shows the power flow of the system on the day of January 22, 2016 on a simulated grid return, where the system is reconnected to grid power.

Figure 29: Microgrid System Power Flow, 1/22/16

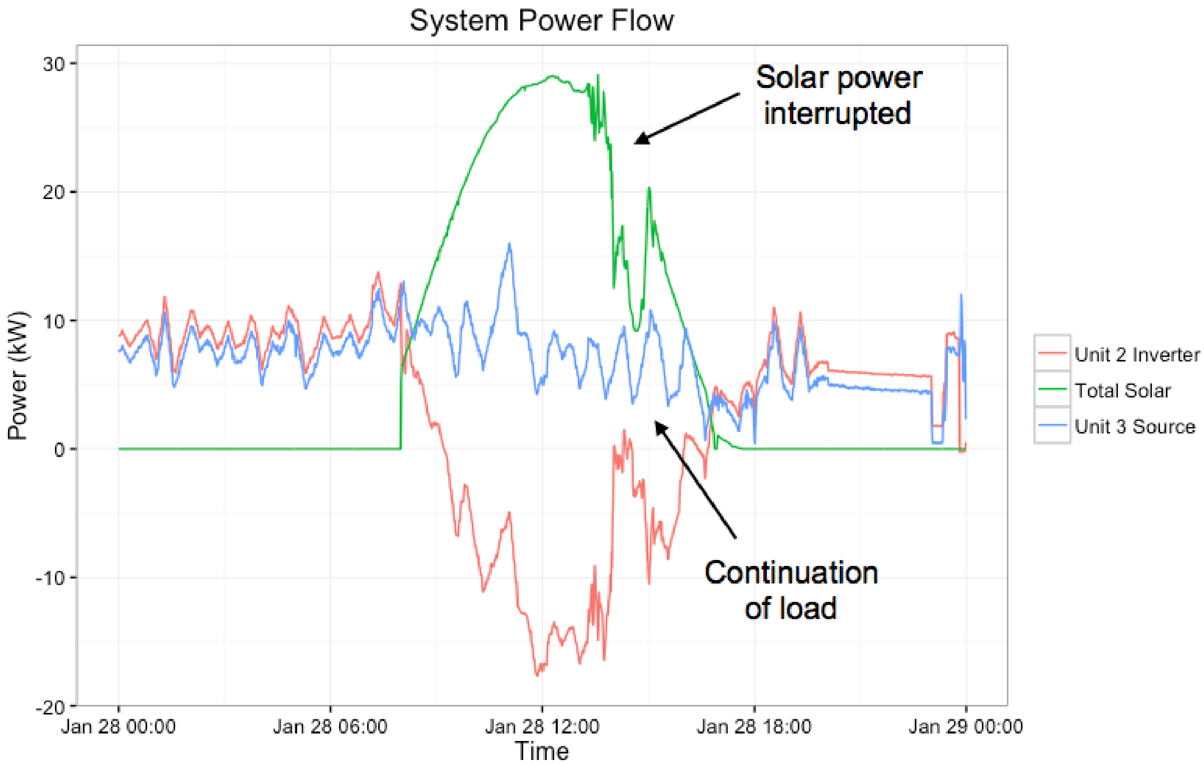


Initially, Unit 2 supplies all necessary power to the load. Just before 9:15pm, the generator power begins ramping up, unstably increasing up to 30kW. Throughout this ramp-up process, Unit 2 is able to quickly compensate for these power fluctuations to provide a net constant power out to the load. While the generator is operating at full power, Unit 2 again acts as a buffer from the generator power for the load.

5.2.2.3 Islanding/Solar Firming

In this scenario, the system is completely disconnected from the grid, as the generator is turned off. The energy storage system both supplies power to the load at nighttime, and also provides solar firming power management during the daytime. Solar firming occurs when there is an unexpected disruption in solar power output, and the system must compensate to keep the load uninterrupted. This compensation comes in the form of power dispatched from the energy storage source to load as solar output decreases, and vice-versa if solar output is higher than the load demand. This effect was observed for several days in testing; one example is presented below in Figure 30. In this example, the load is running off of solar and battery power only (i.e. no generator supply) for 24 hours.

Figure 30: Solar Firming System Power Flow, 1/28/16



Before sunrise, Unit 2 supplies all of the energy required for the load. During the daytime, the battery acts as a buffer for the load during over generation. However, there appears to be a disruption in the solar power output for ~1.5 hours in the afternoon. During this time, Unit 2 supplies the necessary power by reducing the amount stored in the battery (and thus increasing the amount supplied to the load). At some instances, energy is actually dispatched as a net flow out of the battery, even during solar production, in order to maintain the load profile. At night, Unit 2 continues to supply the load demand as the sole source of power in the system.

5.2.2.4 Conclusions of Microgrid Testing Program

Geli successfully controlled the charge and discharge of the Imergy Power System units to perform microgrid tasks, including power management of the system during grid power outage and return, and islanding operations via management of intermittent solar PV power. These functions were performed using the capabilities of the EOS to automatically monitor, control, and manage the energy system, via the Microgrid Operations Energy App. The system was able to operate independent of any grid power, which is of high importance to the NBVC's security and grid independence.

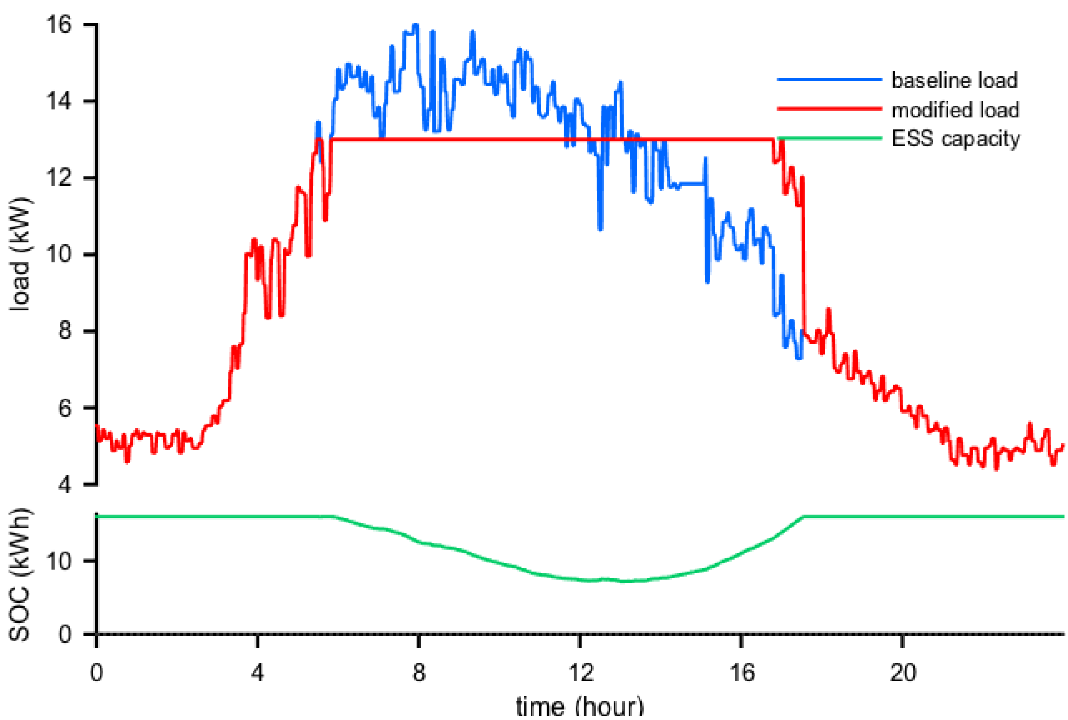
5.2.3 Demand Charge Management Testing

Demand Charge Management, or DCM, is the act of limiting demand charges by limiting the amount of power that is used from the grid to meet the load. This is accomplished by dispatching power from the energy storage system to the load, such that the power from the grid is limited at or below a threshold power. This threshold power is set such that the system avoids demand charges for using power greater than that amount. The Geli DCM Energy App is deployed and used for this purpose. This testing was essential to validating the performance and efficacy of the Geli EOS via the DCM Energy App, so that this Energy App can be improved and utilized in future systems. Testing across several consecutive days, preferably at least one month, are typically required to utilize the full capabilities of the algorithm and verify its efficacy. However, due to limitations of the integration with the Imergy Power System units, only one day was allotted for testing of the DCM app.

5.2.3.1 Test Summary

This test uses the Geli DCM Energy App within the testing system. A load profile, denoted as "load before DCM", is supplied to the load battery system (Unit 3), which is based off of real building load profile data. Also supplied to Unit 3 is a DCM threshold power. The energy storage system (Unit 2) supplies power to Unit 3 to meet the load profile, while keeping the generator input power below the DCM threshold. Figure 31 shows an example of this process for a smaller, 16 kWh battery systems.

Figure 31: DCM Operational Example



During DCM, the generator input ("modified load") is kept at a maximum of 13 kW, while the 16 kWh battery discharges to meet the load demand. The battery then charges once the load decreases below the threshold, to ensure that the battery remains fully charged at the end of the day.

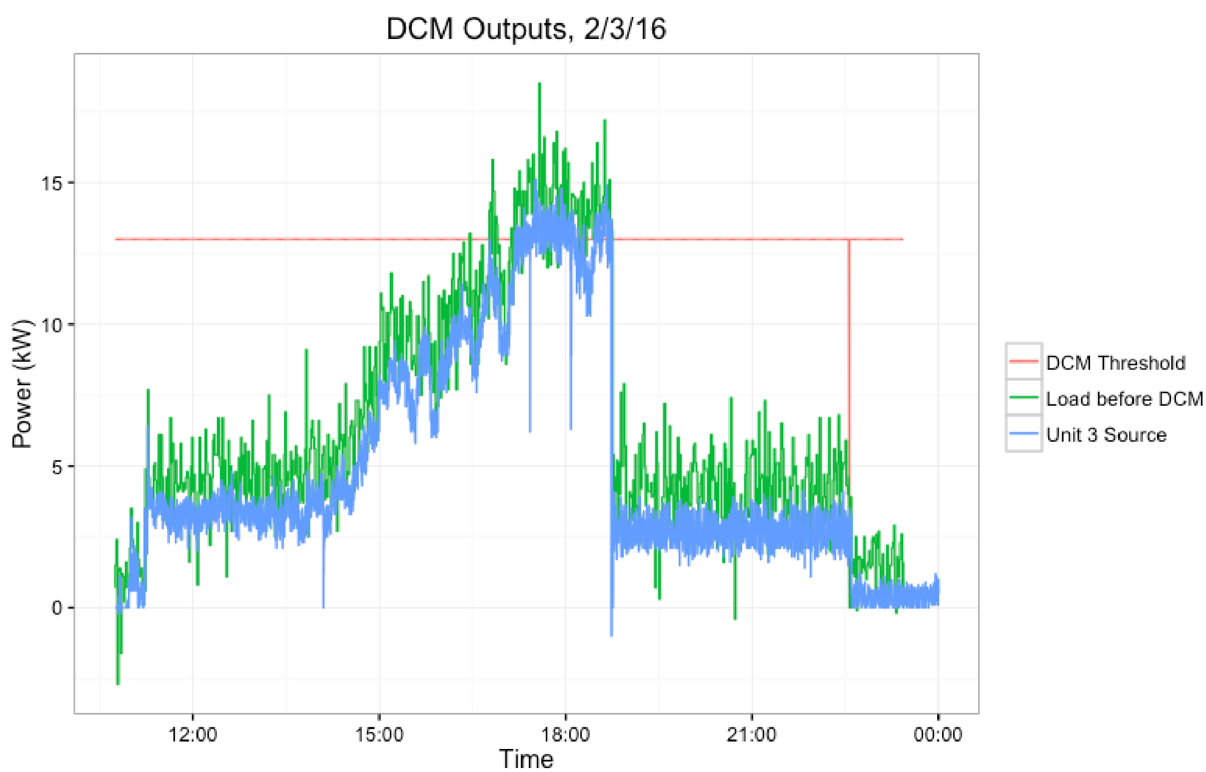
5.2.3.2 DCM Testing

In this test, the DCM Energy App uses the Operational Example from section 5.2.3, with some modifications due to the system size. The DCM threshold remained set at 13 kW, and the load profile was also intended to follow the profile in the preceding section. However, the algorithm input capacity is scaled up from 16 kWh to match the 180 kWh capacity of the Unit 2 battery.

5.2.3.3 DCM Energy App Outputs

Figure 32 shows some of the outputs of the Geli DCM Energy App on the system for the test date of 2/3/16.

Figure 32: DCM Outputs, 2/3/16

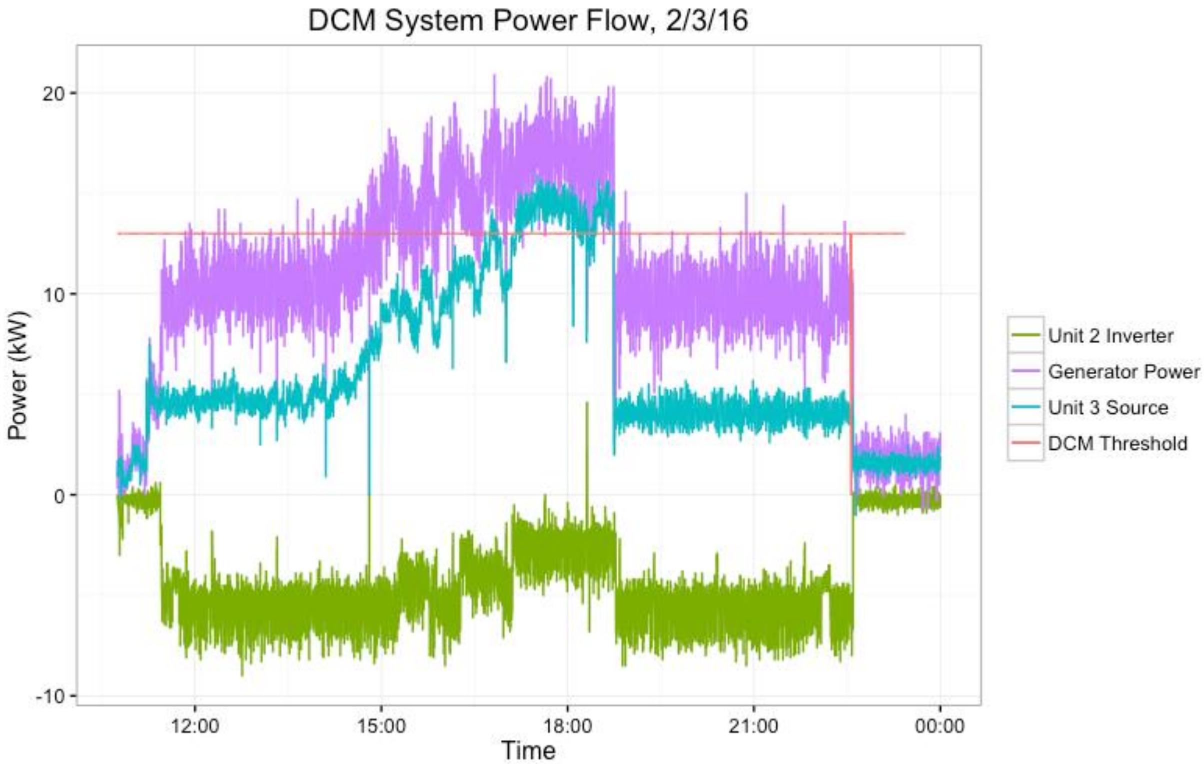


The "Load before DCM" profile did not successfully match the intended load profile from Figure 5.11 in Section 5.2.3. The load stops following the intended load profile at 6:45pm, and instead provides a load that fluctuates between 0-7kW. However, the actual load on Unit 3 ("Unit 3 Source") successfully followed the "Load before DCM" profile. The figure also shows that the load on Unit 3 exceeds the DCM threshold; therefore, the DCM Energy App will need to limit the power contribution from the generator.

5.2.3.4 DCM System Power Flow

Figure 33 shows the system power flow for the test date February 3, 2016, using the above load profile in Section 5.2.3.3. Note that the DCM threshold is still set at 13 kW.

Figure 33: DCM System Power Flow, 2/3/16

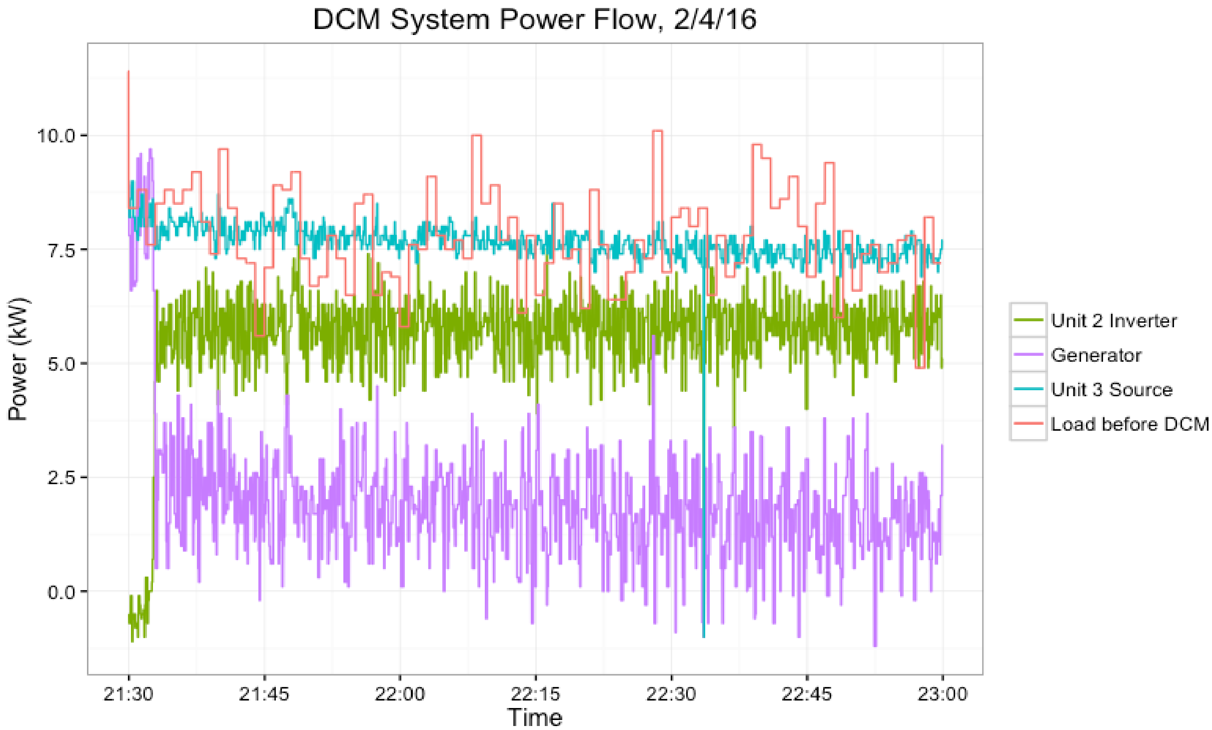


Instead of dispatching energy to Unit 3 when the load exceeds the DCM threshold, Unit 2 instead charges from the generator. This increases the generator power well above both the load profile and the 13 kW threshold. Once the generator surpasses this threshold, the battery does begin charging at a slower rate, which decreases the generator power and brings it closer to the load power, but it is still greater than the threshold. At approximately 10:30 pm, the DCM threshold faulted to 0, which effectively limited all power in the system.

5.2.3.5 DCM Observation

Another possible use of DCM behavior was observed on February 4, 2016. Though a threshold was not reached, Unit 2 dispatched power to supply the load on Unit 3, reducing power needed from the generator. Figure 34 shows the system power flow during February 4, 2016. Note that the load profile successfully follows the “load before DCM” profile.

Figure 34: DCM System Power Flow, 2/4/16



After 9:30pm, Unit 2 switches from charging from the grid to dispatching power to the Unit 3 load. While the load remains above 7 kW, the contribution from the generator is limited below 5 kW, while most of the power is supplied from Unit 2.

5.2.3.6 Conclusions of DCM Testing Program

Geli was unable to successfully control the charge and discharge of the Imergy Power System units to perform DCM in the short allotted time of 1 day, though DCM-like behavior was observed the following day. A longer testing period would have allowed for troubleshooting, calibration, and configuration of the algorithm, leading to a more accurate and efficient performance. In addition, because DCM is a very precise and time-dependent process, improvements to the Imergy Power System, as noted in section 3.1.5, would also improve the efficacy of the DCM algorithm.

CHAPTER 6: Achievement of Goals and Objectives

6.1 Goals

The goals of the amended Grant Agreement and Work Statement are as shown in the numbered items, shown in bold below. The bulleted items below address at a high-level the degree to which these goals were achieved by the project.

1. **Demonstrate the technical and cost-effectiveness of a modular, community-scale, flow battery storage technology that is paired with solar PV generation and interconnected to a microgrid with "islanding" capability at the Expeditionary Warfare Center's (EXWC's) Mobile Utilities Support and Equipment (MUSE) facility at the Naval Base Ventura County.**

   - The project team designed, installed, commissioned and successfully tested a flow battery and solar microgrid project at the NBVC, MUSE facility, demonstrating the technical and operational feasibility of the project technology configuration in both islanded and grid-connected modes.
   - Extensive economic modeling conducted during the Facility Study phase of the project estimated that utility cost savings in the range of 30% would be achievable based on the specific utility tariff and detailed usage profile of the MUSE facility through dispatch of the project in grid-connected mode, assuming anticipated technical performance levels for project components. The limited operational testing conducted during project operations indicated that the assumed technical performance levels and projected cost-savings would be achievable.
   - Demonstration of on-going operational cost-effectiveness was hampered by an inability to complete a sufficient number of test cycles before the grant period expired and the Navy required removal of the project.

2. **Demonstrate that the Project and technology configuration can deliver multiple benefits in both grid-connected and islanded modes of operation:**

   a. **In grid-connected mode: maximize penetration of local renewables; provide substantial utility cost-savings.**

      - Inclusion of flow batteries of sufficient long-duration storage capacity in a microgrid architecture allowed build-out of renewable generation to maximum level permitted by local physical site constraints.
      - Such storage can act to both absorb excess renewable generation beyond current load, as well as buffer intermittent renewable generation and facility loads, such that dramatic short-duration swings in facility net load are not passed up to the grid. Such facility/community level net-load buffering and renewable ramp rate control, if widely adopted along with behind-the-meter renewable generation

installations statewide, would mitigate major sources of short-duration grid instability, thereby facilitating maximum renewable penetration in California.

- The Facility Study and accompanying spreadsheet analysis of specific MUSE facility loads indicate that substantial utility cost-savings, in the range of 20% to 30% percent, are achievable through the deployment of an appropriately sized hybrid microgrid system in grid-connected mode, via the avenues of grid energy displacement, load-shifting, and demand charge management, given the high demand charges and steep time-of-use energy price SCE tariff structure applicable at the NBVC. Various equipment sizing scenarios and optimizations were run, investigating the relative impact on capital costs and utility cost-savings. These results were partially validated given the limited testing cycles remaining once the final project was fully commissioned.

b. **In islanded mode: local energy security, renewable firming, enhanced grid stability and disaster recovery capability (local and grid level resilience).**

- Several full and partial diurnal test cycles of the installed project demonstrated that microgrid could reliably serve local loads from a combination of real-time PV generation and battery provided power. Additionally, the system was able to maintain consistent service to loads through periods of substantial intermittency/instability of renewable generation, thus successfully demonstrating "solar firming" capability.

- The microgrid successfully took over service of critical local loads during grid outages, with only a momentary drop of load and was able to reconnect to the grid and return loads to grid service without load disruption, thereby demonstrating its viability as back-up power supply, without the need for additional fossil-fueled generation.

3. **Create a modular community-scale renewables/storage/microgrid technology configuration that can be replicated across a broad range of communities delivering benefits mentioned above.**

- Created a flexible spreadsheet model for facility load and utility cost analysis, as well as microgrid system component sizing that can be used to vet and predict technical and economic performance of new renewables/storage/microgrid projects.

- This spreadsheet model can be used to analyze loads and design hybrid microgrid systems to meet the needs of a broad range of California facilities and communities.

6.2 Objectives

Although the project's primary storage technology vendor, system architecture and key features changed over the course of the project, the project team selected the replacement primary storage technology/vendor so as to keep the project objectives essentially the same. These are listed in the numbered items below, highlighted in bold. The bulleted items below each objective address the degree to which it was achieved by the project.

1. **Design, develop, and deploy an innovative hybrid project that integrates 150 kilowatts (kW) of solar PV and a modular 100 kW/1000 kW-hr flow battery energy storage system BESS with a microgrid serving the MUSE facility at the NBVC.**
    - The project team was successful in designing, developing, commissioning and partially testing an innovative hybrid microgrid project including the designated technologies.
    - The capacities of the technologies installed varied from the objectives as follows:
        - Solar PV capacity installed was 42 kilowatts. Direct grant funded capacity was reduced from 50 kW to 42 kW due to site space constraints. The additional 100kW was to be provided as a matching contribution by the Navy, as part of its Microgrid Test Bed (MTB) project, which was delayed beyond the limits of this grant program.
        - Imergy flow battery capacities installed: 105 kW, 420 kWh
        - The microgrid infrastructure installed was not connected to the MUSE facility, once again due to the fact that the grid interconnection and intertie to the MUSE facility was within the scope of the Navy's delayed MTB project.
2. **Measure, analyze, and document the capital and operating costs of the hybrid project.**
    - The capital costs of the project were analyzed and documented as part of the project budget tracking.
    - Due to the limited operating time available within the Grant window, prior to decommissioning, we were not able to record or analyze actual operating costs. However, operating costs were estimated and analyzed as part of the completed Operating and Economic Model.
3. **Verify round-trip efficiency of the vanadium-redox flow BESS of 75 percent or more while supporting the microgrid in both grid-connected and islanded modes.**
    - DC to AC round-trip efficiencies of 75.5% were recorded for the Imergy VRF batteries during the performance-testing phase. Please see the Data Collection & Analysis section herein for more detail.
4. **Quantify various operational parameters in terms of power quality (voltage support, and frequency regulation), response time, and operational availability and runtime achievable in island mode.**
    - Performance data for the project system were obtained through the Geli EOS interface. The datasets comprise of data taken at 1-second intervals for the entire system across the testing period and include voltage, power, SOC, and other

important metrics.

- Geli successfully controlled the charge and discharge of the Imergy flow batteries units to perform microgrid tasks, including power management of the system during grid power outage and return, as well as island-mode operations via real-time co-optimization of intermittent solar PV generation and battery dispatch to meet loads.
- These functions were performed for multiple 24-hour periods using the capabilities of the EOS to automatically monitor, control, and manage the energy system, via the Microgrid Operations Energy App.
- The system successfully operated in island-mode, independent of grid signal, maintaining system frequency and voltage. Battery dispatch response times were sufficient to firm significant sub-minute interval intermittency from the PV generation while maintaining system stability and consistent power to loads.

5. **Demonstrate and quantify cost savings to the MUSE facility and NBVC through displacement of utility electrical supply via renewable energy deployment, BESS-enabled load-shifting, and peak-shaving.**

   - Extensive economic modeling conducted during the Facility Study phase of the project estimated that utility cost savings in the range of 20% to 30% would be achievable based on the specific utility tariff and detailed usage profile of the MUSE facility through dispatch of the project in grid-connected mode, assuming anticipated technical performance levels for project components. The limited operational testing conducted during project operations indicated that the assumed technical performance levels and projected cost-savings would be achievable.

CHAPTER 7: Benefits to California

There were numerous benefits achieved by the project including advancing science, technology and practical technology integration of PV's; introducing advanced technologies to build relationships with military early-adopters; modeling quantitative benefits such as utility cost-savings; and, providing successful technology demonstrations with California Business Entities and individuals currently active in microgrid, energy storage and controls manufacture, development and integration.

Most importantly, the project demonstrated that renewable microgrid architecture, supported by long-duration battery storage, simultaneously mitigates grid instability and balances timescale issues and ability to size the systems from the smaller, localized distributed facility/community level to the statewide grid level. The project also created a community-scale, renewable microgrid model that could be replicated across a variety of communities to maximize renewable penetration at the community microgrid level and statewide grid level, for more stable, secure and disaster-resilient communities and utility grids.

7.1 Advancement of Science and Technology

- Proof of concept & template for other California communities/rate payers regarding renewable powered, island-ready microgrids at the facility/community scale.
- Showed modular level CAES, not yet ready for commercialization.
- Validated viability of vanadium redox flow batteries in long-duration, modular format for microgrid applications.
- Identified and solved detailed technical issues around integration of inverters, power electronics and microgrid controls in both grid-connected and islanded modes of operation.

7.2 California Business Entity Capacity Building

- Developed key deployment and operation experience for automating renewable energy systems on a military base. The project was successfully built and operated in accordance with military operations and procedures.
- Geli expanded its capability to control solar inverters and energy storage inverters at the same site under a single digital control system. Such architectures are being seen in deployments more regularly and this project gave Geli, PDE, and Foresight experience in deploying and operating PV solar with storage systems (PVS). The PVS architectures are increasingly being used for distributed renewable energy deployments.
- This project utilized the Geli Energy Operating System that was designed for flexibility of hardware and applications. This project allowed Geli to advance standardization of Geli's Microgrid Product stack.

- Geli needed to work closely with the military base to enable proper and secure communications. This insight helped Geli further develop technology security and operation security standard procedures.

7.3 Utility Cost-Savings

Several test cycles in grid-connected mode demonstrated that the Geli system controller was capable of peak-shaving and time-shifting of loads via battery system dispatch. Extensive modeling of System performance using measured MUSE loads and the applicable Southern California Edison tariff structure conducted during the Facility Study phase of this project indicated that substantial levels of utility savings would be achievable at the MUSE facility, given these capabilities at the tested levels. With optimal scaling of PV generation and battery storage capacities, the modeling indicates that grid-connected utility savings in the 30% or greater range would be achievable for facilities or communities under current SCE C&I tariff structures.

CHAPTER 8: Conclusions

- Validated through installation and testing the ability to create an island-ready microgrid to serve critical loads indefinitely with PV Solar generation only, including providing sufficient solar firming.
- This hybrid configuration effectively maximized renewable penetration at MUSE facility level, utilizing all the allocated by the Navy for PV deployment
- Equipment costs were relatively high at time of project implementation compared to the present. However, even at these higher costs, economically optimized scenarios still had simple payback periods in the range of three years, if used year-round in resilience mode. Since project implementation costs have been dropping dramatically, while integration and functionality has been improving across all key system components. Paybacks and reliability of similar systems are expected to be dramatically better.
- The above suggests that such systems can and could now be economically deployed broadly across California and nationwide, creating island able microgrids with some level of renewable powered "indefinite survivability" in the event of serious disaster and protracted grid outages.
    - Such systems can be deployed at the single facility, campus, office park, or distribution feeder level.
    - Initially such deployments could be focused to support critical facilities, such as medical services, first responders, food and water supply, emergency response and shelters, police and military, telecommunications.
    - Deployments could then move toward factories, offices, restaurants, residences and entire community level distribution feeders.
    - Each such microgrid would constitute a quantum of local resiliency, vastly improving emergency preparedness and grid-level disaster recovery.

CHAPTER 9: Recommendations

9.1 Lessons Learned

The following recommendations are based on lessons learned during project deployment and may provide useful guidelines to help defray risk of failure for future projects, both grant funded and otherwise.

- Initial technology selection should be limited to technologies that have multiple fully functioning beta versions in operation. Had FRS applied this screen when selecting its storage vendor, the project could have saved over a year aggregate grant implementation schedule.
- Technology vendors who are geographically close improve efficiency of collaboration. Choice of the South African inverter vendor by Imergy created major delays in trouble-shooting and final commissioning.
- Details of technology integration across complex hybrid systems is no small task. When possible use vendors who have worked together previously. The more participants that have done so, the faster the integration is likely to go. Current market leaders in installation of hybrid solar/storage and microgrid systems such Tesla and Geli report that technology and vendor integration remains the most difficult hurdle to the commercial advancement of the microgrid sector.
- Including Military, or other large governmental or institutional participants, particularly if relied on for deployment of critical infrastructure, should be expected to result in unexpected delays and risk to project success. Communication across such large organizations and hierarchies is cumbersome, approval cycles long, and grant-funded projects that are relatively small compared to overall organizational operations should be expected to be low on the organizational priority list.

9.2 Technology Insights

The following recommendations are based on perspectives gained on technology during project implementation and may be useful in guiding choice of subject for future Energy Commission grant-funded research.

- Microgrid control networking: island able, renewable-powered microgrids not only provide locales of internal grid stability and energy security:
    - They may be networked with the local/regional utility to provide services back to the larger distribution and transmission grid, thereby improving local and regional power quality and grid stability. Geli has continued to develop microgrids as both a solution to help provide stable power at an apartment complex in St. Croix, to provide dispatchable grid services for the Las Positas Community College in Livermore CA, and for a utility partner in Auckland, Austrialia. This Navy project

helped Geli by providing military experience that is desirable to our Utility partners who value security and capability.

- If proximal to and directly electrically interconnected with one another, microgrids may also be directly networked with each other at the controls level to share resources and loads, thereby mutually enhancing the energy security, renewable penetration, power quality and resiliency.

- Grid architecture: hybrid microgrids as locales or quanta of resiliency may form the "self-healing" nodal web architecture of the internet, where traffic is automatically rerouted around any outages at any particular node or nodes.
- Flow Batteries are being increasingly identified as good long-term equipment solutions since their hardware promises to qualify as a 20-year asset and their liquid electrolyte can either be recharged without degradation, as with VRF batteries, or the electrolyte can be replaced as needed. This is unlike Li-ion batteries that typically have a limited number of charge discharge cycles leading to critical hardware degradation over the first 10 to 15 years project life. Flow Batteries are also being proven to have a low cost of operation on a Levelized Cost of Energy Storage (LCOES). Flow Batteries should not be overlooked and it is recommended that proper tools and demonstrations be performed where Flow Batteries are investigated as a way to meet economic considerations in microgrid projects.

The power converters used in the Imergy system caused difficulty. There is much research and product development that is required in the realm of power converters and their fundamental controls. Further, Flow Batteries are often low voltage due to their chemistry. High power systems are often high voltage and can cause issues for Flow Batteries. There need to more options available to the market for flexible DC voltage inputs on 50, 100, 150, and 250kW power converters so they can interface to Flow Batteries. Alternatively, there need to be high power DC-DC converters that can link low Voltage Flow Batteries with High Voltage DC rails of power converters.

GLOSSARY

Term	Definition
BESS	Battery Energy Storage System
CPM	Commission Project Manager
CPR	Critical Project Review
DCM	Demand Charge Management. Reduction of demand charges by deploying energy storage.
EOS	Energy Operating System. Geli proprietary software platform, which controls and manages the energy storage system, as well as reads and stores data from the energy storage system.
EPC	Engineering, Procurement and Construction
EXWC	Engineering and Expeditionary Warfare Center. EXWC is a division of NAVFAC
FRS	Foresight Renewable Solutions
GELI	Growing Energy Labs, Inc.
Islanding	Operation of the demonstration project in periods of utility grid outage, and/or when intentionally disconnected from the utility grid
kW	Kilowatts. kW are “capacity” (power that can be produced at a given instant)
kWh	Kilowatt hour. kWhs are “energy” (amount of power produced over time)
Load shifting	Storing energy from solar PV generation, off-peak grid supplied energy, or other energy and dispatching such energy from BESS during peak energy usage periods when utility rates are highest
MTB	Microgrid Test Bed. Navy project to install microgrid and PV generation infrastructure at the MUSE facility. The MTB was originally expected to be contemporaneous with this Project, but fell far behind schedule.
MUSE	Mobile Utilities Support and Equipment. MUSE is a facility at NBVC of the EXWC.
NAVFAC	Naval Facilities Engineering Command
NBVC	Naval Base Ventura County
Peak	Dispatch of solar PV and/or BESS during peak capacity demand periods,

shaving	leading to a reduction in demand charges from the utility
PDE	Pacific Data Electric, Inc.
PV	Photovoltaic
SOC	State of Charge. Presented in this paper as a percentage of full battery capacity. 100% denotes a fully charged battery, while 0% is fully discharged.